

DISTRACTION OSTEOGENESIS OF THE FACIAL SKELETON

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DISTRACTION OSTEOGENESIS OF FACIAL SKELETON

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“So many are the links, upon which the true Philosophy depends, of which, if anyone be loose or weak, the whole chain is in danger of being dissolv’d; it is to begin with the Hands and Eyes, and to proceed on through the Memory, to be continued by the Reasons; nor is it to stop there, but to come about to the Hands and Eyes again, and so, by continual passage round from one Faculty to another, it is to be maintained in life and strength, as much as the body of man is by the circulation of the blood through the several parts of the body, the Arms, the Fat, the Lungs, the Heart, and the Head.”

Hooke, *Micrographia*, 1567

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PREFACE

The focus of this book is the treatment of patients with dentofacial and craniomaxillofacial deformities, which defy correction by immediate repositioning of the facial bones. Maxillofacial deformity patients with congenital, post tumor ablation, post traumatic defects, and temporomandibular joint deformities are all potential candidates for distraction osteogenesis.

Because craniomaxillofacial (CMF) surgery remains evolutionary, the surgeon's training is a continuum. During the past 10-15 years, quantum leaps have occurred in this very dynamic and ever-changing field with the introduction of computer aided surgical simulation, new surgical and orthodontic technologies and surgical alternatives.

With increased healthcare costs, decreased reimbursements, excessive treatment time and high liability, the use of orthognathic surgery has declined thereby leaving many facial deformity patients untreated. The evolution and development of distraction osteogenesis and histogenesis has provided the essential missing link in the management of these patients.

A paradigm shift in the way surgeons and orthodontists treat dentofacial deformities will revitalize Orthognathic surgery. Patients with deformity treated by accelerated orthognathic surgery, distraction osteogenesis procedures, or surgical alternatives, planned by three-dimensional imaging technology and new technologies designed to correct CMF deformities, can be done more efficiently, rapidly and predictably at affordable fees in outpatient surgical centers. This paradigm shift will significantly impact the way surgeons and orthodontists treat patients with CMF deformities.

The challenge of increasing mandibular ramus height and increasing arch width in the esthetic zone are predictably treated by slow expansion of the maxilla and mandible. Simultaneous three-dimensional repositioning of the maxilla and mandible are possible by a combination of immediate movement and distraction osteogenesis. High midfacial craniomaxillofacial surgery has been revolutionized by the use of distraction osteogenesis. What was once risky, unpredictable and morbid procedures are presently short, safe and predictable.

Distraction histogenesis has solved the significant problems of surgical repositioning the cleft maxilla by slow stretching of the enveloping skin tissue to facilitate movement of the maxilla into a normal anatomic relationship with the rest of the face.

Early treatment by distraction osteogenesis of either the neonate with compromised airway or the adult severe sleep apnea in an ambulatory center is frequently not only lifesaving, but safe and predictable.

A specialty derives its standards from selected individuals who emerge to take their place in history. We have attempted to select some of these individuals who have made and will continue to make a significant impact on the specialties of oral and craniomaxillofacial surgery. Each contributor is active and dynamic in a particular field of interest in distraction osteogenesis. This book describes the work of visionaries, creative thinkers, and pioneers who dared to take "the first step". Through their efforts, our specialty continues to move forward to new heights. We owe an enormous debt to the multi-specialty contributors of this book.

After 50 years in oral and maxillofacial surgery, I continue to depend on the efforts of others. We build on the past, and we are all the products of our parents, our teachers, our colleagues, and the talents and challenges that God provides us.

To men like Dr. Sumpter Arnim, Dr. Barnet M. Levy, Dr. Edward C. Hinds, Dr. Robert V. Walker, and Dr. H. Gilbert Triplett. I am deeply indebted – these men have provided me the opportunity and environment both to continue animal and clinical investigations and participate in the clinical arena. I also want to thank Dr. Harry Schwartz and Dr. Stephen Chu for their ongoing encouragement and assistance.

I have had the privilege of working with young and very talented oral and maxillofacial surgery residents in our research laboratory at the University of Texas Health Science Center at Dallas and Baylor College of Dentistry: Drs. John J. Dann, Raymond J. Fonseca, Stephen A. Schendel, James W. Kennedy, Heidi Opdebeeck, Richard A. Finn, John A. Brammer, Gregory B. Scheideman, Scott B. Boyd, Craig C. Johnston, Michael R. Warner, Kenneth A. Storum, Hideaki Nagura, Jaime G. Quejada, Hiroshi Kawamura, Joseph Schoenaers, Xien Zhang, Philip Washko, Silas DeTulio, Waldemar Polido, Aurora Morino, Yoshinoro Yamaguchi, David Darub, Nestor Karas, Chawket Mannai, Zhihao You, Lecio Pinto, Marianela Gonzalez, and my son, Bryan.

I want to extend special thanks to many dental and medical colleagues who have entrusted the surgical care of their patients to me during the development phase of orthognathic surgery and distraction osteogenesis. By their support and close collaboration, these colleagues have made possible some of the present surgical advances.

Special thanks must be extended to the unsung heroes who have helped prepare the manuscript – Maria Reyes, the ever patient and kind editor at BC Decker Inc., Brian C. Decker who had confidence in the project, Bill Winn, Javier Matos, and Richard Gonzalez, for their excellent medical illustrations, Drs. Ruben Trujillo and Oscar Guerrero in Caracas, my daughter, Christine, her husband, Lucky, and grandchildren, Brittney and Nicholas for their constant computer assistance, and lastly for my wife, Sherry, who has been my faithful in-house backup secretary for 43 years.

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Three-Dimensional Facial Treatment Planning

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The quality of facial outcomes produced with occlusal correction can be less than ideal. Model-based diagnosis, cranial base cephalometrics, lack of a facial measurement system, and lack of occlusal plane control contribute to poor facial outcomes. This occurs with orthodontic and surgical treatments (Figures 1-1 and 1-2).

Unfortunately, reliance on cephalometric analysis and treatment planning can sometimes lead to esthetic problems.¹⁻⁶ The assumption that bite correction based on cephalometric standards leads to correct facial esthetics is *not* always true and may in some instances lead to less than desirable facial outcomes.¹⁻⁹ Michiels and Tourne studied the validity of cephalometric analyses, which measure cranial base landmarks.⁸ The cranial base proved unreliable for determining correct diagnoses and therefore treatment plans for dental corrections. Another source of cephalometric inaccuracy is that each cephalometric study holds different measurements as the key to diagnosis. Wylie and colleagues

demonstrated clearly that dissimilar cephalometric analyses when used on the same patient indicate different diagnoses and treatment plans.³ Another problem with cephalometric diagnosis and treatment planning is that the normal values may not be accurate because of different soft tissue posturing. In some studies, the soft tissues were not in a repose position when measurements were made.^{6,10-16}

Diagnosis and treatment planning based on model analysis are less accurate than predicting facial changes on a cephalometric basis. When bite changes are made solely on dental model assessment, the facial result can be negative. How prevalent is orthodontic diagnosis based entirely on model examination? Han and colleagues reported that 54.9% of treatment decisions in their study were based on models and no other diagnostic information.¹⁷ When models determine the treatment plan, how often does facial decline occur? Drobocky and Smith studied 160 cases of orthodontic four-bicuspid extractions

treated to Class I (models).¹⁸ They found that 15% of the lips were excessively flat and 30.6% of the nasolabial angles were excessively obtuse ($>120^\circ$), and Class I treatment produced poor facial outcomes in one-third of the cases (33%). Models are inadequate for facial treatment planning. They provide no information regarding the pretreatment facial condition or the influence of bite correction on facial change.

Some practitioners do not systematically examine the face prior to making treatment planning decisions. This may be due in part to not having facial harmony as a treatment goal. Total reliance on cranial base cephalometrics or model examination may involve other reasons, or it could be that the practitioner simply does not deem facial measurement helpful to overall treatment planning.

Patients who have steep occlusal planes often have convex, chin recessive, unattractive profiles. A steep occlusal plane may be natural or secondary to orthodontic and surgical



FIGURE 1-1 Patient N.B. was initially treated to a Class I occlusion with orthodontics only; this included bicuspid extractions and headgear, over a 5-year period. Her chief complaint before orthodontic treatment was her lack of chin projection. A complete focus on correcting her occlusion without treating her facially resulted in facial disharmony and patient dissatisfaction. A, Surgical consult profile. B, Surgical consult frontal.



FIGURE 1-2 In these photos, C.E. is 8 months postoperative from Le Fort I and bilateral sagittal osteotomies, and chin augmentation. Note the excessive nasal base projection and the disproportionate projection of pogonion relative to the soft tissue B point and to the lower lip anterior, all of which reflect a bimaxillary posterior impaction (clockwise rotation) with a compensating genioplasty. A, Postoperative frontal. B, Postoperative profile repose.

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manipulation. Nasal base and chin projection is largely dependant on the occlusal plane. Steepening of the occlusal plane increases nasal fullness and decreases chin projection. If these are not desirable facial changes, then the occlusal plane should not be steepened in an attempt to avoid counterclockwise rotations of the mandible (Figure 1-2).

Excellent facial esthetics can be obtained by employing a three-dimensional facial treatment approach (Figure 1-3). This approach combines both clinical facial analysis and soft tissue cephalometrics (Figures 1-4 through 1-8), as reported by Arnett and colleagues.^{6,19-21} Anteroposterior and vertical treatment planning is accomplished with a seven-step cephalometric treatment plan (CTP), as described by Arnett and colleagues.^{20,21} Spatial relationships as defined by the clinical facial analysis, soft tissue cephalometric analysis, and CTP are then used to determine model surgery movements in three dimensions using the SAM 3 articulator and Erickson Model Block (Great Lakes Orthodontic, Ltd, Tonawanda, NY) (Figure 1-9).

First, the clinical facial examination is performed on patient J.M.^{6,19,21} The patient is viewed in natural head position, lips relaxed, seated condyle position, and first tooth contact. Important anteroposterior, vertical, midline, level, and

outline features of the face are recorded in an organized fashion (see Figure 1-4). Anteroposterior and vertical measurements are then used to direct the CTP. Clinical examination of facial projections (anteroposterior) is subjective but excellent for assessing contours of various areas such as the cheekbones and nasal base. All clinical vertical assessments are objective, as they are accurately measured with a ruler. Midline, level, and outline information are used to direct Erickson Model Block surgery to correct problems in these dimensions. Midlines and levels can be measured, whereas the outline is interpreted subjectively. It should be noted that the clinical facial examination is the only source of midline, level, and outline information guiding treatment planning in those spatial dimensions.

The soft tissue cephalometric analysis (STCA) is then performed with patient J.M. in natural head position, first tooth contact, lips relaxed, and condyles seated.^{20,21} The true vertical line is established, as described by Arnett, to measure projections of the face. A wax bite is fabricated prior to taking the cephalometric radiograph to insure that the mandibular position is accurate. The STCA is used to measure hard and soft tissue structures, as documented by Arnett and colleagues.^{20,21} This analysis measures facial projections of the high midface, maxillary, and

mandibular areas. Harmony between the total face, orbital rim, maxilla, and mandible is measured, giving guidance to projection planning. Additionally, dental and skeletal structures that determine the height of the face are measured.

Data from the clinical examination and STCA guide the CTP anteroposterior and vertical changes for patient J.M. The CTP consists of seven steps. The initial two steps involve setting the upper and lower incisor inclinations ideally to the maxillary and mandibular occlusal planes, respectively. Steps 3 and 4 involve correcting the overbite (incisor and molars) and overjet. These first four steps correct the occlusion to Class I, but have yet to address the patient’s facial esthetics. Steps 5 through 7 direct the position of the bimaxillary Class I complex in order to achieve maximum facial harmony. Step 5 moves the maxillary incisor tip in ideal esthetic vertical and anteroposterior position in relation to the upper lip. This position is based on data from the clinical examination and STCA. Step 6 involves correction of the occlusal plane to esthetically adjust both the nasal base and chin projections. As part of the occlusal plane step, the entire maxillomandibular complex can be moved anteriorly or posteriorly, as needed, to improve the nasal base and chin position. Step 7 involves performing a genioplasty, as necessary, for chin projection, level, and/or height adjustments.

The models for patient J.M. are mounted on the SAM 3 articulator in natural head position, paralleling the X and Y axes of the clinical examination, the STCA, and the CTP. Measurements from the CTP are then transferred to the Model Block surgery to accomplish the planned anteroposterior and vertical changes. Midlines and cants are set on the Model Block as indicated by the clinical examination.

Patient 1

J.M., an 18.9-year-old female with a severe Class II steep occlusal plane and anterior open bite, was treated with a multi-segment Le Fort I osteotomy (MSLFI), bilateral sagittal split osteotomy (BSSO), chin augmentation, upper lip VY reconstruction, nasal floor lowering, and PRP with bone grafts to both jaws. The treatment was designed to correct facial imbalances, increase the airway, and correct the occlusion, as described above. The diagnosis and treatment plan were derived using the three-dimensional treatment planning flowchart (see Figure 1-3). This patient was not treated with distraction osteogenesis. The before and after occlusal and facial changes are shown in Figure 1-5. The three-dimensional facial analysis for J.M. is shown in Figure 1-4. Her STCA and CTP are shown in Figures 1-6 and 1-10.

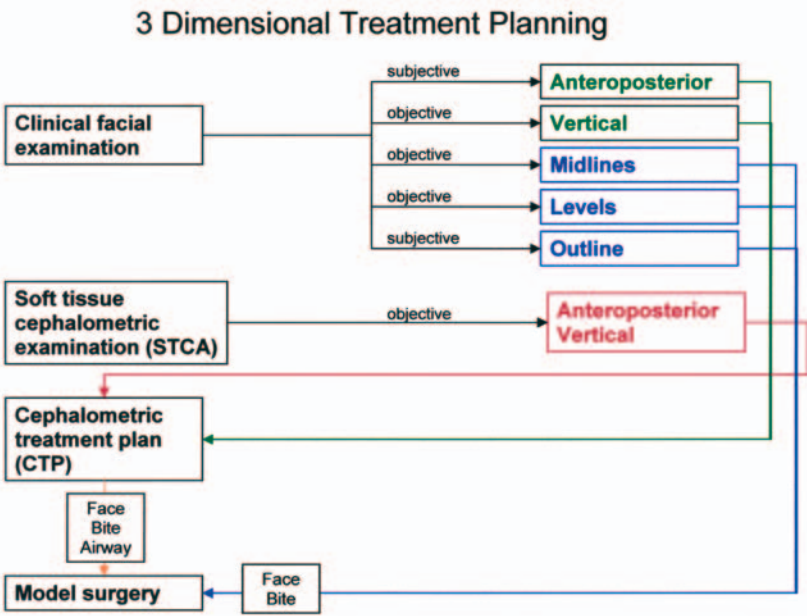


FIGURE 1-3 Three-dimensional facial treatment flowchart. The clinical facial examination (green) plus soft tissue cephalometric analysis (STCA) (red) combine to direct anteroposterior and vertical cephalometric treatment planning (CTP). Midlines, levels, and outline are solely determined with the clinical facial examination (blue). The cephalometric treatment plan (orange) is then used to determine anteroposterior and vertical model surgery, whereas midlines, levels, and outline determine those aspects of model surgery (blue). All surgical movements as determined by STCA and clinical facial analysis are created within the model surgery to optimize facial, bite, and airway changes. Note: subjectivity and measurability are indicated with each aspect of examination.

FACIAL EXAMINATION

Name

age

orthodontist

FRONTAL VIEW

1. vertical	range	patient	possible ways to normalize vertical		
overbite	3 mm	-1	LFI	BSSO	crown length change
upper lip height	19-22 mm	20			orthodontics crown torque change
interlabial gap	1-5 mm	10	LFI	BSSO	lip length surgery
lower lip height	42-48 mm	40	LFI	BSSO	overbite correction
lower 1/3 height	60-68mm	70	LFI	BSSO	lip posture change
Mx incisor exposure (relaxed)	1-5mm	10	LFI	BSSO	chin osteotomy – change height
Mx incisor exposure (smile)	8 crown to 2 gingiva	10	LFI	BSSO	submental lipectomy
closed lip	strain less touch	10	LFI	BSSO	chin osteotomy – change height
Mx incisor height	9.5-11.5 mm	9.5	LFI	BSSO	crown length change
upper vermillion	6-9 mm	6	LFI	BSSO	lip length surgery
lower vermillion	8-12 mm	10	LFI	BSSO	crown torque change
middle 1/3	60-68mm	60	LFI	BSSO	gingivectomy

2. vertical planning
Mx1 plan-relaxed lip: current relaxed exposure 10.5 ± desired change -7.5 = goal 3.0 (> 5 mm advancement anticipated? yes increase impaction)
Mx1 plan-smile lip: current smile exposure 7.0 ± desired change -7.5 = goal 9.0 (> 5 mm advancement anticipated? yes increase impaction)
facial plan: ± Mx1 height change -7.5 ± overbite change -2 ± chin height change 0 = net -9.5 OK outline - interlabial gap

3. midlines	patient	possible ways to normalize facial midlines	
nasal tip	to right 0 to left 0	LFI	LFI-shorten septum isolated septoplasty
philtrum	to right 0 to left 0		soft tissue midline which dental midlines are measured to
Mx 11	to right 0 to left 0	LFI	orthodontics canine cant change
Md 11	to right 1 to left 1	BSSO	orthodontics canine cant change
chin	to right 1 to left 1	BSSO	chin osteotomy canine cant change

4. facial levels	patient	possible ways to normalize facial levels	
eyes	R down 0 L down 0	visualize cant Y N	none
Mx canines	R down 0 L down 0	visualize cant Y N	LFI orthodontics
Md canines	R down 0 L down 0	visualize cant Y N	BSSO orthodontics
Md body level	R down 0 L down 0	visualize cant Y N	BSSO heat treated HA augmentation
chin level	R down 0 L down 0	visualize cant Y N	BSSO chin osteotomy

5. outline	patient	possible ways to normalize outline	
general	round wide narrow long short √normal	LFI BSSO advance	overbite change chin osteotomy – change height buccal or submental lipectomy
zygomatic arch	R larger wide √normal narrow narrow √normal wide larger L		HA augmentation reduction osteoplasty
Md angle	R larger wide √normal narrow narrow √normal wide larger L	BSSO	midline rotation canine cant cold cure HA graft
Md body	R larger wide normal narrow normal wide larger L	BSSO	midline rotation canine cant cold cure HA graft
chin	narrow wide wide lip angular short long	posture change	chin osteotomy cold cure HA buccal lipectomy
alar base width *	alar base width 34 mm intercanthal width 28 mm		alar base stretch surgical narrowing

PROFILE

1. high midface projection	patient	ways to normalize high midface projection	
glabella	protruded √normal retruded		osteoplasty
orbital rim	flat soft √normal prominent R larger L larger		heat cured HA augmentation
cheekbone	flat soft √normal prominent R larger L larger		heat cured HA augmentation reduction osteoplasty
subpupil	flat soft √normal prominent R larger L larger		LFI (MSLFI advances more than LFI) heat cured HA

2. maxillary projection	patient	ways to normalize soft tissue nasal base – upper lip projection	
nasal base	concave flat soft convex prominent R larger L larger	LFI	desired could move 2-3 mm anterior
ULA to TVL	retruded normal protruded straight Mx sulcus lip: thin thick	LFI	11 torque change lip thickness change
upper lip support	weak normal strong support: air teeth gingiva	LFI	11 torque chng desired could move 6-7 mm anterior
orthodontics 1	12-17 4475 est headgear elastics RPE functional	LFI	11 torque chng buccal buccal plane
orthodontics 2	age extractions headgear elastics RPE functional	LFI	11 torque chng buccal buccal plane
nasal projection	long normal short tip: up down dorsal: hump saddle	LFI	rhinoplasty

3. mandibular projection	patient	ways to normalize lip and chin projection	
LLA to TVL	retruded normal protruded 11 deflection accent flat labiomental fold	Mx11 torque change LFI able Mx11 torque change	
Pog' to TVL	retruded normal protruded	BSSO	steeper or buccal buccal plane chin augmentation or reduction
throat length	short normal long chin line sag	BSSO	steeper or buccal buccal plane chin augmentation or reduction
4. overjet	8 mm	does not indicate source of malocclusion	orthodontics LFI BSSO

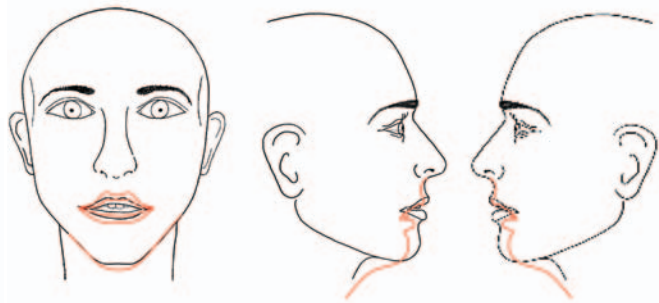


FIGURE 1-4 Three-dimensional clinical facial examination form. Important traits in three dimensions are listed in the left-hand column. Normal values, where applicable, are listed next to the important traits. Patient J.M. is measured and recorded in the yellow column. In this example, abnormal findings are recorded in red. The right-hand green area contains treatment possibilities for each abnormal finding. Again, in this example, the patient's desired treatment is highlighted in red. Red outline on drawings show patient in relaxed position. Reproduced with permission from Arnett Facial Reconstruction Courses Inc.; 2006.

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FIGURE 1-5 Patient J.M. Presurgical and 23 months postsurgical occlusal and facial photos are shown. *Ai*, Presurgery introduction. *Aii*, Postsurgery introduction. *Bi*, Presurgery profile closed lip. *Bii*, Postsurgery profile closed lip. *Ci*, Presurgery profile repose. *Cii*, Postsurgery profile repose. *Di*, Presurgery profile smile. *Dii*, Postsurgery profile smile. *Ei*, Presurgery front closed lip. *Eii*, Postsurgery front closed lip. *Fi*, Presurgery front relaxed lip. *Fii*, Postsurgery front relaxed lip.



FIGURE 1-5 continued. *Gi*, Presurgery front smile. *Gii*, Postsurgery front smile. *Hi*, Presurgery right three-quarters. *Hii*, Postsurgery right three-quarters. *Ii*, Presurgery left three-quarters. *Iii*, Postsurgery left three-quarters. *Ji*, Presurgery level. *Jii*, Postsurgery level. *Ki*, Presurgery bite right. *Kii*, Postsurgery bite right. *Li*, Presurgery bite front. *Lii*, Postsurgery bite front. *Mi*, Presurgery bite left. *Mii*, Postsurgery bite left. *Ni*, Presurgery bite side. *Nii*, Postsurgery bite side.



FIGURE 1-6 Objective soft tissue cephalometric analysis (STCA) measurement of patient J.M. The STCA reveals maxillary retraction (upper incisors -18), corresponding upper lip retraction (125, -16, -4, -20), mandibular retraction (lower incisors -26), chin recession (-28), a steep occlusal plane (108), and vertical excess (interlabial gap 14, upper incisor exposure 11). Reproduced with permission from Dolphin Imaging, Arnett/McLaughlin Analysis.



FIGURE 1-7 Patient C.M. Before and 35 months postsurgical occlusal and facial photos are shown. *Ai*, Presurgery introduction. *Aii*, Postsurgery introduction. *Bi*, Presurgery profile repose. *Bii*, Postsurgery I profile repose. *Ci*, Presurgery frontal repose. *Cii*, Postsurgery frontal repose. *Di*, Presurgery bite right. *Dii*, Postsurgery bite right. *Ei*, Presurgery bite frontal. *Eii*, Postsurgery bite frontal. *Fi*, Presurgery bite left. *Fii*, Postsurgery bite left.



FIGURE 1-8 Patient NB. Before and 16 months postsurgical occlusal and facial photos are shown. *Ai*, Presurgery introduction. *Aii*, Postsurgery introduction. *Bi*, Presurgery profile repose. *Bii*, Postsurgery profile repose. *Ci*, Presurgery frontal repose. *Cii*, Postsurgery frontal repose. *Di*, Presurgery bite right. *Dii*, Postsurgery bite right. *Ei*, Presurgery bite frontal. *Eii*, Postsurgery bite frontal. *Fi*, Presurgery bite left. *Fii*, Postsurgery bite left.



FIGURE 1-9 Sam 3 articulator model surgery for patient J.M. The mandible is operated first to enhance the accuracy of the anteroposterior, levels, and mid-lines at surgery. The intermediate splint, made from the new position of the mandible, is used to accurately orient the bimaxillary complex in three planes.

Bone grafts were harvested with the Osteo Harvester (Osteomed LP, Addison, Texas) from the cheekbones, the anterior nasal floor, and above the chin osteotomy line. The nasal floor was lowered to prevent the upper lip from following the superior repositioning of the anterior maxilla. Both jaws were advanced and rotated counterclockwise (see Figure 1-10). The total pogonion advancement was 28.6 mm, with 3.3 mm of this due to chin augmentation (see Figure 1-10).

Possible relapse was addressed in multiple fashions. Six months presurgically and for 1 year postsurgically, the temporomandibular joints were stabilized with doxycycline, vitamins C and E, and amitriptyline.^{22–26} A short split BSSO was achieved to insure that the masseteric sling stayed on the condylar-bearing fragment. No clamping was used between the condylar- and tooth-bearing fragments during fixation, to avoid possible clamp torquing of the condyles.^{27,28} Bivector seating was used to prevent posterior displacement of the condyles, as described by

Arnett and colleagues.^{27,28} Mandibular fixation was achieved with two long OsteoMed BSSO plates with four 6 mm screws per plate. To decrease postoperative perimandibular connective tissue pressure^{29,30} on the condyles, a suprahyoid myotomy was done, long Class II elastics and anterior skeletal elastics were used.

Patient 2

C.M., a 26.6-year-old female with rheumatoid arthritis, was treated using the three-dimensional treatment planning flowchart (see Figure 1-3). Six years prior to our treatment, C.M. had undergone a Le Fort I (LFI) osteotomy with posterior impaction and chin augmentation.

Before and after occlusal and facial changes are shown in Figure 1-7. The CTP in Figure 1-11 demonstrates the treatment plan for C.M.: bimaxillary counterclockwise rotation with advancement and chin augmentation. This patient was not treated with distraction osteogenesis.

C.M.’s surgery and relapse control were the same as those of Patient 1, with some notable exceptions. Her medication management was altered for her rheumatoid arthritis. One year presurgically and 2 years postsurgically, the temporomandibular joints were stabilized with doxycycline, vitamins C and E, feldene, methotrexate, simvastatin, and enbrel. Iliac crest bone graft and Interpore 200 blocks were used to downgraft the back of the LFI. C.M. underwent two equilibrations postsurgically to maximize intercuspation and increase the overbite.

Patient 3

N.B., a 32.3-year-old female, was treated using the three-dimensional treatment planning flowchart (see Figure 1-3). N.B. had undergone extensive orthodontic treatments without surgery in an attempt to correct her bite prior to our work-up and treatment.

Before and after occlusal and facial changes are shown in Figure 1-8. The CTP in Figure 1-12 demonstrates the treatment plan for N.B.: bimaxillary counterclockwise rotation with advancement, chin augmentation, and buccal lipectomy. N.B.’s surgery and relapse control were the same those of Patient 1. This patient was not treated with distraction osteogenesis.

Conclusion

The determinants of a successful outcome in orthognathic surgery are occlusion, facial harmony, and airway patency. Fanatical focus on individual diagnostic tools such as cranial base cephalometrics, model analysis, occlusal plane angle, or hard-to-soft tissue ratios blinds the practitioner to the factors that actually determine facial outcome.

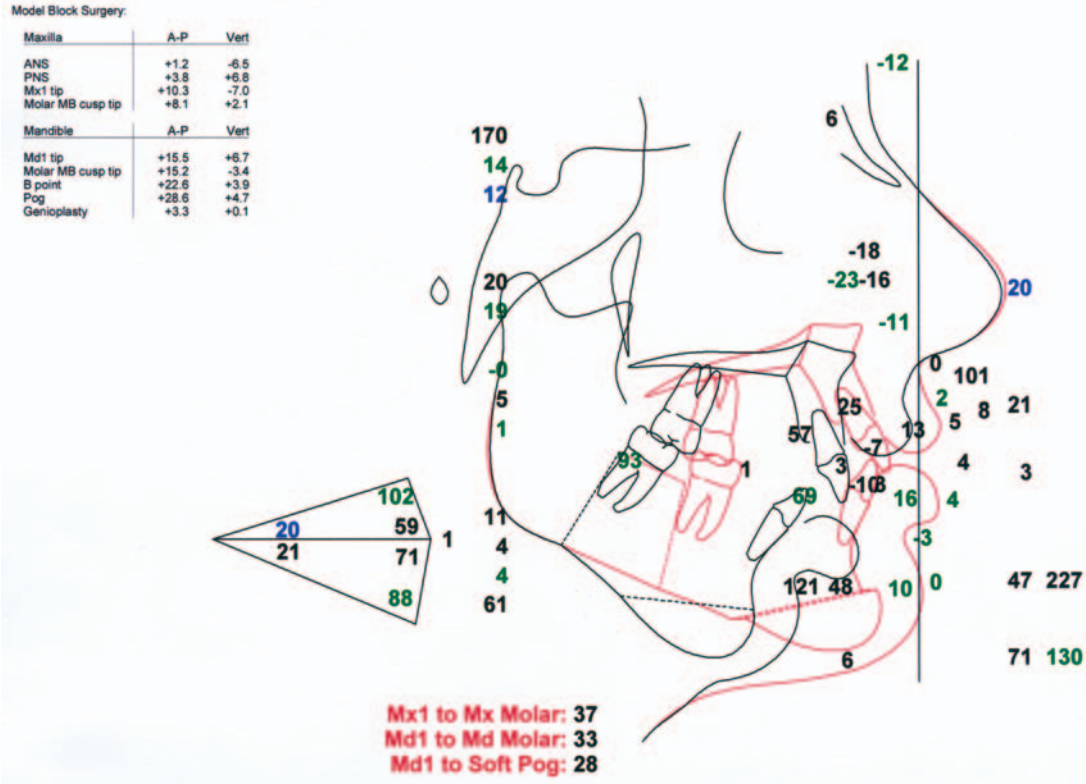


FIGURE 1-10 Objective cephalometric treatment planning for patient J.M. The black tracing represents presurgery. The red tracing depicts vertical and anteroposterior treatment goals for the occlusion, face, and airway. Note that the occlusal plane was flattened from 108° to 93°, requiring a counterclockwise rotation of the maxilla and mandible, which produced esthetic support at the alar base and projection of the chin. The total advancement at pogonion was 28.6 mm, of which 25.3 mm was produced via mandibular advancement and 3.3 mm from the chin osteotomy advancement. Reproduced with permission from Dolphin Imaging, Arnett/McLaughlin Analysis.

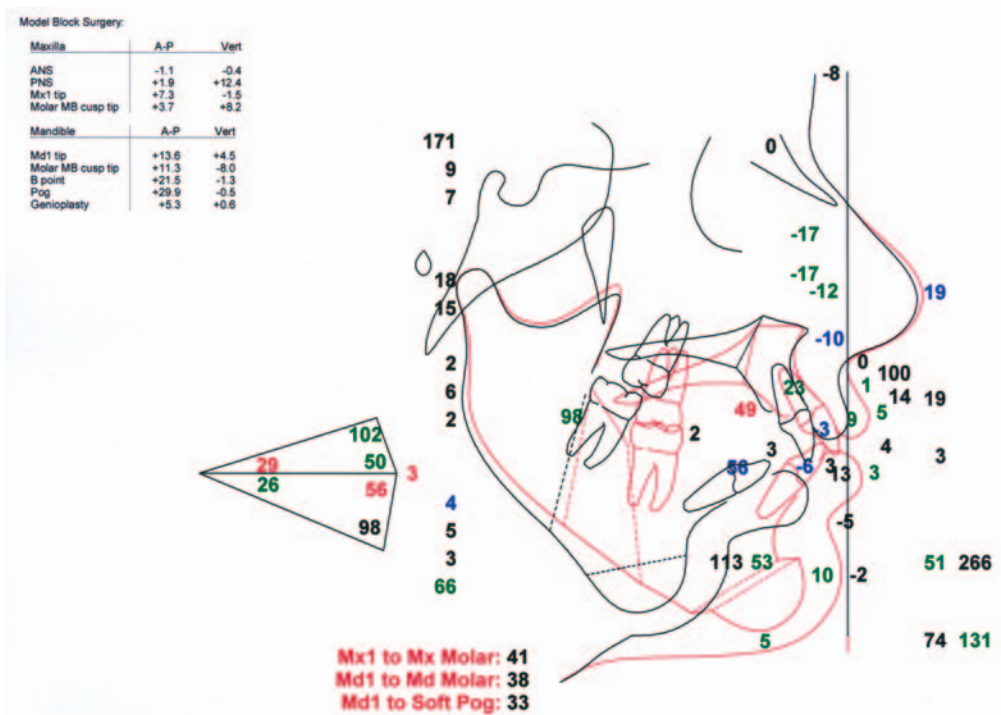


FIGURE 1-11 Objective cephalometric treatment planning for patient C.M. The *black* tracing represents presurgery. The *red* tracing depicts vertical and anteroposterior treatment goals for the occlusion, face, and airway. Note that the occlusal plane was flattened from 113° to 98°, requiring a counterclockwise rotation of the maxilla and mandible, which produced esthetic support at the alar base and projection of the chin. The total advancement at pogonion was 29.9 mm, of which 24.6 mm was produced via mandibular advancement and 5.3 mm from the chin osteotomy advancement. Reproduced with permission from Dolphin Imaging, Arnett/McLaughlin Analysis.

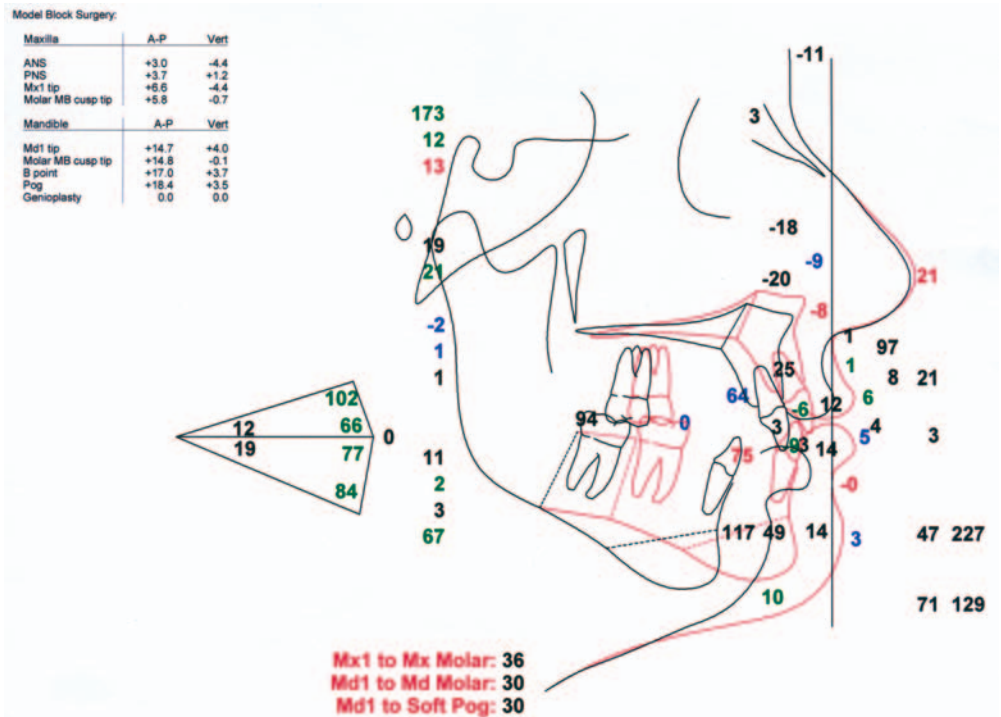


FIGURE 1-12 Objective cephalometric treatment planning for patient N.B. The *black* tracing represents presurgery. The *red* tracing depicts vertical and anteroposterior treatment goals for the occlusion, face, and airway. Note that the occlusal plane was flattened from 100° to 94°, requiring a counterclockwise rotation of the maxilla and mandible, which produced esthetic support at the alar base and projection of the chin. The total advancement at pogonion (Pog') was 18.4 mm and was produced via mandibular advancement. Note the lower one-third projection disharmony secondary to the lower bicuspid extractions and resulting incisor retraction relative to pogonion. This disharmony is apparent in the left-hand column of harmony numbers (-2 Sn to Pog', 1 A' to B', 2 lower lip to Pog'). Reproduced with permission from Dolphin Imaging, Arnett/McLaughlin Analysis.

A timely and cogent example would be the standard surgical treatment for a Class III patient: mandibular setback with or without maxillary advancement. The treatment plan addresses the occlusion (models) and cranial base standards, but oftentimes the chin throat length is minimized, the nasal base remains flat, and/or the patient is left with a pencil thin airway, thus inducing sleep apnea. More often than not, the Class III patient needs bimaxillary advancement for occlusal correction, facial harmony, and airway patency.

A more prevalent example is the treatment of Class II open bite patients with posterior maxillary impaction. For the sake of "stability," the steep mandibular plane angle is made steeper, the normal nasal basal is made excessively prominent, and the recessive chin is addressed with a large unesthetic chin augmentation. Surgeons persist with dogmatic avoidance of counterclockwise mandibular movements in spite of studies showing that it is cosmetically superior and is quite stable.³¹⁻³⁴ Additionally, Gidarakou and colleagues have shown that Class II malocclusions secondary to retarded condylar growth are associated with steep occlusal planes, mild maxillary retrusion, and greater mandibular retraction.³⁵ According to these data, impaction of the posterior maxilla in these patients would be inappropriate because of a preexisting steep occlusal plane. In addition, from a mechanical standpoint, Tanaka and colleagues showed that intracapsular temporomandibular joint stress is 1.2 to 4 times greater with steep mandibular planes (ie, steep occlusal planes).³⁶ It is possible then that posterior impactions of the maxilla (clockwise rotations) can increase temporomandibular joint stress and promote degenerative changes of the temporomandibular joint.

This chapter has presented a means of approaching the patient in an organized manner. Systematic clinical examination, soft tissue cephalometric analysis, CTP, and accurate model surgery all insure proper occlusion with ideal facial harmony and a patent airway.

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2A

Formation and Mineralization of Maxillary Membranous Bone during Distraction Osteogenesis

Adi Rachmiel and Dina Lewinson

Distraction osteogenesis results from slow pulling apart of two bone edges of a low-energy fracture (subperiosteal osteotomy) with an external fixator that mechanically creates a gap in which new bone regenerates between the two edges.^{1,2} Bone created through the use of distraction osteogenesis provides a particularly attractive substrate for histologic study in both enchondral bone³⁻⁵ and membranous bone.⁶⁻⁹ The use of immunohistochemical methods and electron microscopy may contribute to understanding the stages of bone regeneration and neovascularization. The objective of the present study was to follow the events of bone formation and neovascularization during maxillary distraction and introduce it as a model paradigm for intramembranous bone formation. The understanding of these interactive processes contributes to the development of new strategies and drugs that will stimulate regeneration of new bone that might improve its quality.

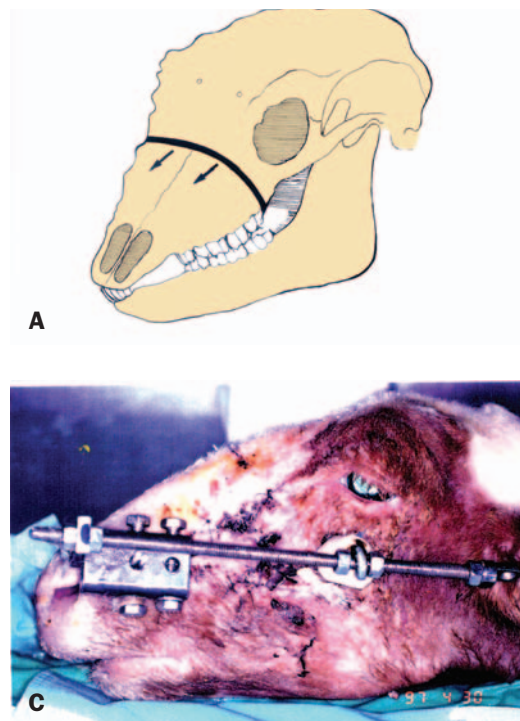
Maxillary osteotomy was performed on five young adult sheep aged 1 year (Figure 2A-1A). A distraction device composed of one main threaded rod on each side of the face was fixed on the pins (Figure 2A-1B). The distraction was made by turning the activation nuts at a rate of 1 mm per day for 20 days. Biopsies were removed under general anesthesia along the osteotomy line after 5 days of latency and after 5, 10, 15, and 20 days of gradual distraction. The last biopsy was taken after an additional 6 weeks of consolidation (without gradual distraction).

The methods used for analysis were light microscopy for histologic and immunohistochemical examination and electron microscopy.

LIGHT MICROSCOPY

General Histology

Paraffin sections, 5 μ m thick, were stained with hematoxylin and eosin for general morphology,



with Masson trichrome stain for visualization of collagen fibers, and with von Kossa's stain for visualization of foci of mineralization.

Immunohistochemistry

Polyclonal antibodies raised against proliferating cell nuclear antigen (PCNA) were used to reveal proliferating cells that are engaged in deoxyribonucleic acid (DNA) synthesis. A positive PCNA staining index was defined as the percentage of stained nuclei from the total number of cell nuclei. PCNA-positive staining index values were calculated together with the mean value and standard errors of measurements for each zone in different biopsies.

Tie-2, a receptor of angiopoietin 1, served as a marker for endothelial cells. Polyclonal

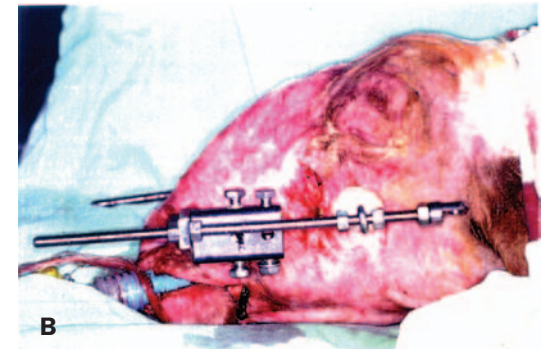


FIGURE 2A-1 A, Illustration of the maxillary osteotomy. The arrows indicate the maxillary anterior movement. B, The animal immediately after surgery with the mounted distraction device before commencement of distraction. C, Midface protrusion after forward distraction. At the end of distraction, the device remained 6 weeks for consolidation.

anti-Tie-2 antibodies were used to identify endothelial cells and cells of vascular origin.

ELECTRON MICROSCOPY

Sections of 80 to 100 nm thick were cut with a diamond knife, placed on #300 uncoated copper grids, and stained with uranyl acetate and lead citrate for observation in a JEOL 100 SX (Jeol, Tokyo, Japan) transmission electron microscope.

RESULTS

After 20 days of forward distraction, the five distracted animals developed maxillary advancement, which was observed clinically (Figure 2A-1C) and radiographically. Integrating all of

the data obtained from the sections that were exposed to the various histologic, histochemical, immunohistochemical, and ultrastructural procedures, the following dynamic events were observed:

At the end of the latency period, 5 days following the osteotomy and just before commencement of distraction, only a mesh of fibrin clot containing blood cells and newly formed capillaries could be observed. Granulation tissue was observed in the margins infiltrating gradually into the fibrin clot (Figure 2A-2A).

After 5 days of distraction (10 days postosteotomy), most of the hematoma was replaced by a heterogeneous population of mesenchyme-like and spindle-shaped cells. Some capillaries transversed the regeneration (Figure 2A-2B). PCNA revealed areas with a high proliferation index of 50% (Figure 2A-3).

Whereas after 5 days of distraction, tissue was quite homogeneous histologically, after 10 days of distraction (15 days postosteotomy), three distinct zones and two transitional areas within the regenerating tissue could be observed:

1. In the midregion of each biopsy, the central zone (CZ), the tissue was composed of unorganized mesenchyme-like and spindle-shaped cells in which many capillaries and venules were dispersed (Figure 2A-4A). The CZ is the latest regenerated area as it shows consistently some positively PCNA-stained nuclei that represent proliferating cells. Therefore, the CZ was called a mesenchymal or proliferative area.
2. On both sides of the CZ are paracentral zones (PCZs), in which the number of cells and capillaries decreased gradually, accompanied by a gradual increase in an intercellular matrix. The matrix consisted of wavy collagenous fibers in which relatively small numbers of spindle-shaped fibroblast-like cells are embedded (Figure 2A-4B). Electron

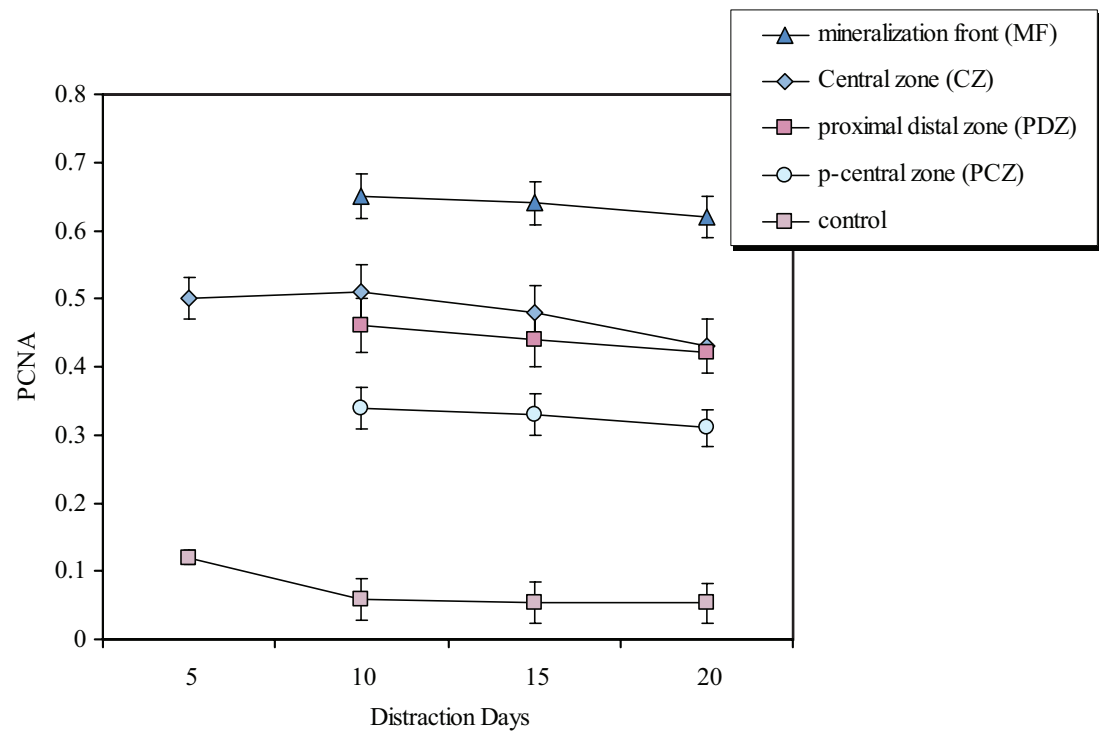


FIGURE 2A-3 The proliferation index (calculated from proliferating cell nuclear antigen [PCNA] positively stained cells as described in Materials and Methods) of different zones of the regenerated tissue at different distraction periods. The greatest positive index value was obtained for the mineralization front area (MF), followed by the central zone (CZ; mesenchymal-proliferative area) and then the proximal-distal zone (PDZ; trabecular-mineralization area) and the paracentral zone (PCZ; fibroblastic-collagenous area). The control nondistracted tissue had a relatively low PCNA labeling index. Zonation was observed from 10 days of commencement of distraction. Means $\pm$ standard error are plotted.

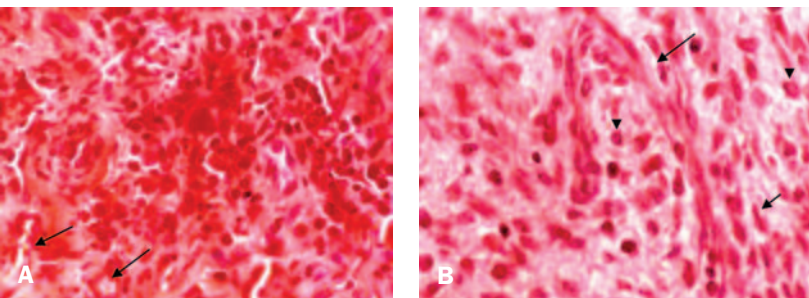


FIGURE 2A-2 A, Five days following osteotomy, before lengthening: the fibrin clot with newly formed capillaries (arrows) and granulation tissue (hematoxylin-eosin stain; $\times 100$ original magnification). B, After 5 days of distraction: replacement of granulation tissue by mesenchyme-like (arrowheads) and spindle-shaped (short arrow) cells. Few capillaries transverse the regeneration tissue (long arrow) (hematoxylin-eosin stain; $\times 100$ original magnification).

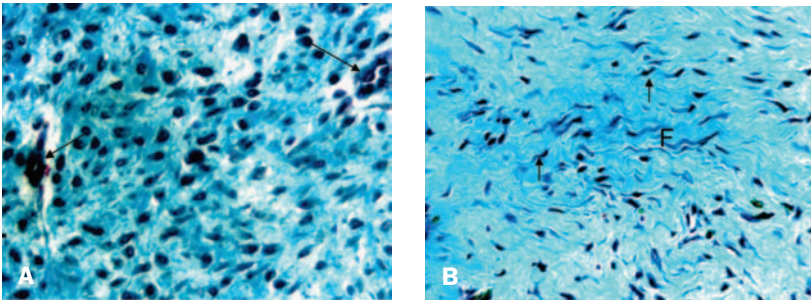


FIGURE 2A-4 After 10 days of distraction. A, The central zone is occupied by mesenchyme-like cells and a few capillaries (arrows) (Masson trichrome stain; $\times 100$ original magnification). B, The paracentral zone is occupied by reduced numbers of spindle-shaped fibroblast-like cells (arrows) that are embedded in wavy collagenous fibers (F).

microscopy shows many apoptotic cells. The PCZ is called a fibroblastic or collagenous area.

In the transition area from the CZ to the PCZ, we observed smaller condensations of mesenchyme-like cells—"onion-like" configurations because of their concentric appearance (Figure 2A-5A). Tie-2 immunohistochemistry stained the inner cells of the concentric colonies and the capillaries invading the regenerating tissue (Figure 2A-5B).

Electron microscopy showed that the onion-like cellular colonies are surrounded by a basement membrane and are composed of centrally located cells, which often show the beginning of lumen formation. The basement membrane also separates the inner cells from the outer cells and envelopes all of the outer cells (Figure 2A-6). These cellular colonies initiate formation of new vessels by

a mechanism of vasculogenesis. Therefore, this transition area is called the vasculogenesis area.

3. Most proximally and distally, the proximal-distal zones (PDZs) were in direct continuation with old bony edges. There we observed delicate new woven bone trabeculae, which became aligned with osteoblasts (Figure 2A-7A). Therefore, the PDZ is called the trabecular or mineralization area. The trabecular tips recruit PCNA-positive preosteoblasts from the collagen-rich distracted tissue (Figure 2A-7B). These preosteoblasts were arranged concentrically around the tips of the trabeculae and have the higher proliferation index (see Figure 2A-3). The preosteoblasts further mature into osteoblasts, which contribute to the trabecular growth. This narrow transitional area between the PCZ and the PDZ is defined as the mineralization front (MF).

Comparing calculated proliferation indexes for different distraction zones at four time points (5, 10, 15, and 20 days), we found that for any time point, the higher index was found in the MF, followed by the CZ, PDZ, and PCZ in succession (see Figure 2A-3). The undistracted control tissue had a significantly lower PCNA labeling index ($p < .05$) compared with those calculated from distracted zones at any time.

After 15 days of distraction, the same zonation is observed. The trabeculae gradually become mineralized. von Kossa's staining showed mineral to be present in the newly formed woven bone (Figure 2A-8A). Some of the newly formed trabeculae are already aligned with osteoblasts.

After 20 days of distraction, the same zonation is observed. The newly formed delicate bone trabeculae continued the nondistracted bone at the osteotomy line and are oriented in the direction of distraction. The trabeculae are rimmed by osteoblasts.

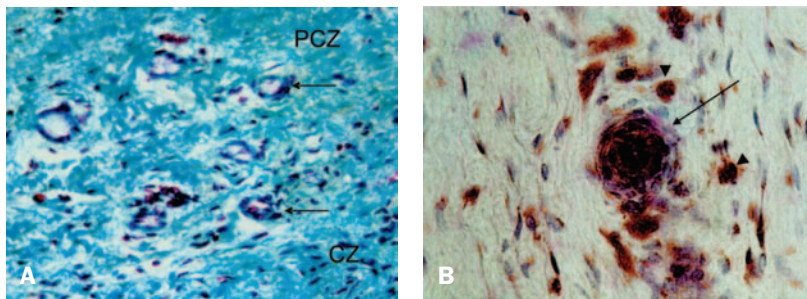


FIGURE 2A-5 A, The transition area from the central (CZ) to the paracentral zone (PCZ): concentric colonies of cells—"onion-like" configurations (arrows) (Masson trichrome stain; $\times 100$ original magnification). B, Tie-2 immunohistochemistry stains the inner cells of the concentric colonies (arrow) and some cells of the surrounding tissue (arrowheads) ($\times 100$ original magnification).

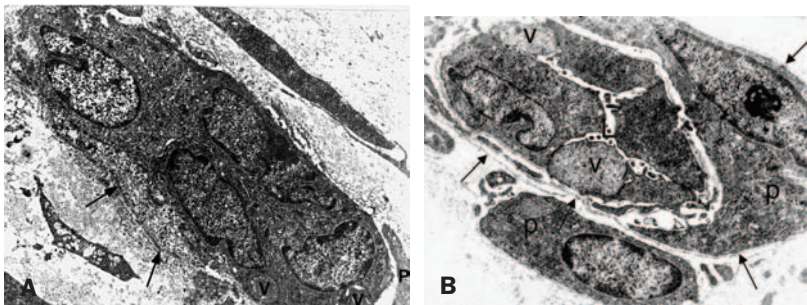


FIGURE 2A-6 Electron microscope photomicrographs. A, Early stage in the development of an "onion-like" complex that consists of five cells recruiting pericytes (P) embedded in basement membrane (arrows); no lumen has yet been formed. Vacuoles with inclusion bodies can be seen (V) ($\times 5,000$ original magnification). B, The beginning of lumen formation (L) in the center of an "onion." Two pericytes (P) and cellular processes lie adjacent to the five central cells. The basement membrane encloses the inner cells and the pericytes (arrows). Large vacuoles (V) might represent disintegrating cells that contribute to lumen formation ($\times 12,000$ original magnification).

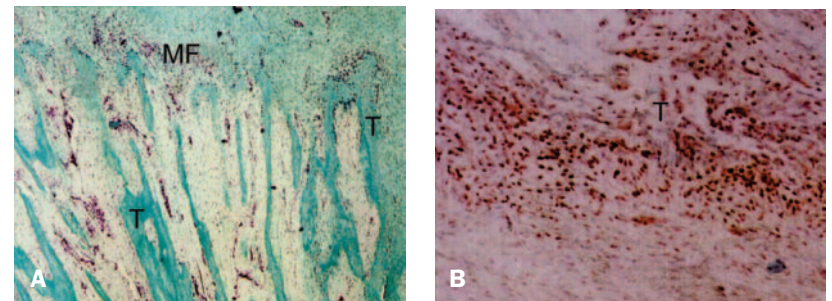


FIGURE 2A-7 A, The proximal-distal zone: delicate new woven bone trabeculae (T) in the direction of lengthening. Their tips form the mineralization front (MF) (Masson trichrome stain; $\times 100$ original magnification). B, Proliferating cell nuclear antigen immunohistochemistry: recruitment of proliferating preosteoblasts (stained brown) to the trabecular tips (T) at the mineralization front ($\times 100$ original magnification).

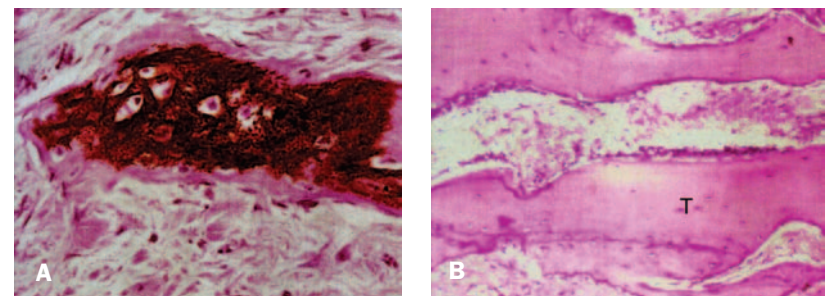


FIGURE 2A-8 A, After 15 days of distraction: von Kossa staining demonstrates mineral content in the center of a trabecula in which bone cells are embedded ($\times 100$ original magnification). B, After 6 weeks of consolidation: the trabeculae (T) became thicker, mostly lamellar bone, rimmed by osteoblasts ($\times 40$ original magnification).

After 6 weeks of consolidation, there is no zonation as during active lengthening. The bony trabeculae became thicker, with a mixture of woven and lamellar bone, rimmed by osteoblasts and bridging the distracted gap from edge to edge (Figure 2A-8B). Bone remodeling of the newly formed bone by osteoclast resorption was identified histologically and by tartrate-resistant acid phosphatase histochemistry (not shown).

Based on these data, the characterization of midface maxillary distraction is summarized in Table 2A-1 and drawn in Figure 2A-9.

In another study, progressive mineralization developing from the end of distraction to the 1-year follow-up was demonstrated (Figure 2A-10).⁷ There is an increase in calcium and phosphorus content (expressed as counts) measured by electron dispersive x-ray microanalysis from 3 weeks through 10 weeks until 1 year when compared with the nondistracted control area. As can be seen, calcium increased relative to the control nondistracted bone (100%) from 24.3% in 3 weeks postdistraction to 77.8% 6 weeks later and to 95% after 1 year.

DISCUSSION

Understanding the process of early stages of bone formation is obligatory for choosing the nature and timing of any supplementary therapeutic intervention that might be considered in the future.

The objective of this study was to describe and characterize the histologic and ultrastructural features during distraction osteogenesis in the maxillary bone. Clear zonation was seen during active gradual distraction, which during the consolidation period changed to the known longitudinal bone trabeculae rimmed by osteoblasts with bone remodeling of the newly formed bone. The morphologic pattern of maxillary distraction is presented using, in addition, immunohistochemical methods and electron microscopy, demonstrating the early stages in angiogenesis and osteogenesis of the distracted tissue toward mature lamellar bone.

After 10 days of distraction and during all distraction, the regenerated tissue can be divided into three main zones and two transitional areas: (1) a CZ, occupied by many polygonal mesenchyme-like and spindle-shaped cells that proliferate intensively (mesenchymal or proliferative area); (2) two PCZs on both sides of the CZ, in which many cells show morphologic signs of apoptosis, leading to a decreased number of fibroblast-like cells embedded in wavy collagen fibers (fibroblastic or collagenous area); in the transition from the CZ to the PCZ, concentric cellular colonies are believed to be a novel form of vasculogenesis (vasculogenesis area); (3) distal-proximal zones, on both sides of the PCZs

Table 2A-1 characterization of midface maxillary bone formation during distraction
Central zone = mesenchymal or proliferative area
Increased number of mesenchyme-like and spindle-shaped cells
Many capillaries resulting from angiogenesis
In the transition area from A to B: vasculogenesis area:
Mesenchymal condensations and onion-like complexes embedded in basement membrane
Paracentral zone = collagenous or fibroblastic area
Wavy collagenous fibers
Decreased number of fibroblast-like cells, apoptosis
In the transition area from B to C: mineralization front:
Recruitment of preosteoblasts from the distracted area to the trabecular tips
Proximal-distal zone = trabecular or mineralization area
Delicate woven bone trabeculae growing from the edges of old bone oriented in direction of distraction
The trabeculae become aligned with osteoblasts
Bone remodeling
Mineralization of the trabeculae

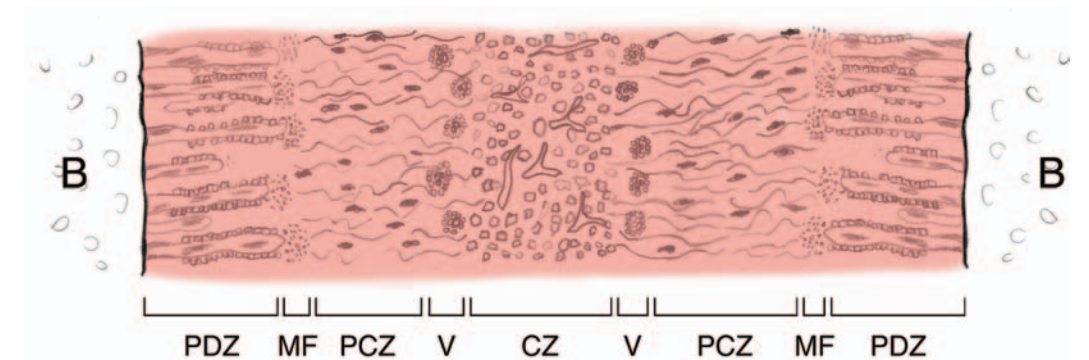


FIGURE 2A-9 Schematic drawing of bone formation during midface maxillary distraction. After 10 days of distraction and during the distraction period, the regenerated tissue can be divided into three zones and two transitional areas: (1) a central zone (CZ): a mesenchymal or proliferative area; (2) two paracentral zones (PCZ): a fibroblastic or collagenous area, from both sides of the central zone; (3) two distal and proximal zones (PDZ): a trabecular or mineralization area. Two transitional areas: the mineralization front area (MF) and the vasculogenesis area (V).

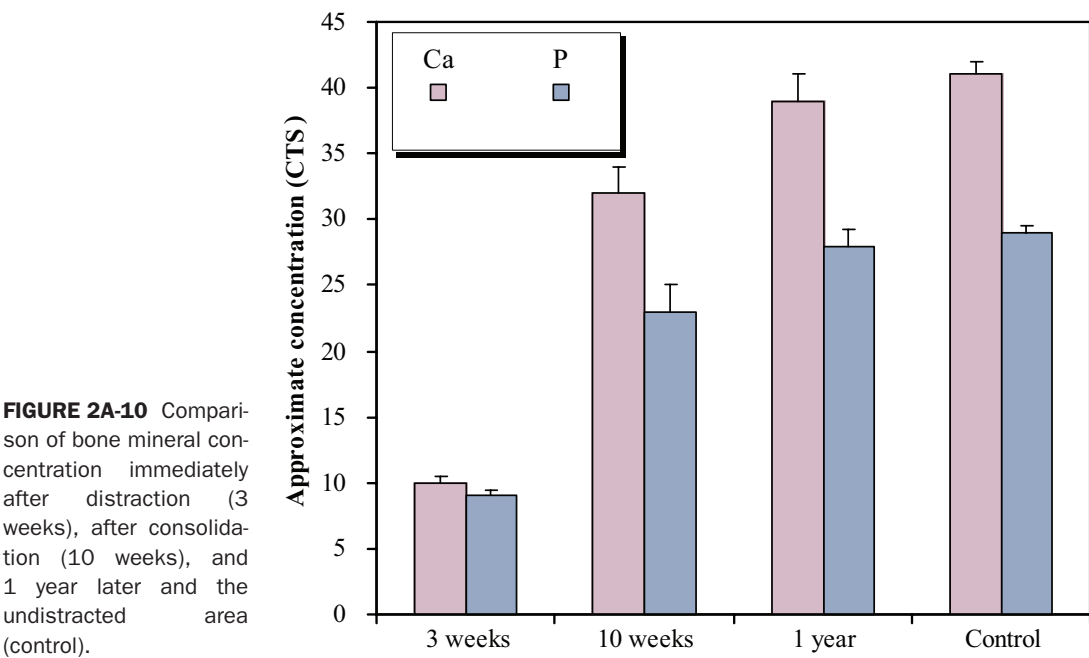


FIGURE 2A-10 Comparison of bone mineral concentration immediately after distraction (3 weeks), after consolidation (10 weeks), and 1 year later and the undistracted area (control).

and in continuation with the old bone, show delicate new woven bone trabeculae that grow continuously in the direction of lengthening and gradually become mineralized (trabecular or mineralization area). In the transition from the PCZ to the distal-proximal zones, there is recruitment of preosteoblasts from the distracted tissue to the trabecular tips (MF), and these further differentiate into osteoblasts, which contribute to the trabecular growth. The histologic feature pattern was similar also after 15 and 20 days of continuous distraction. Between 10 and 15 days of distraction, the newly formed trabeculae started to become mineralized. At the end of lengthening, after 20 days, delicate longitudinally oriented trabeculae continue to grow by recruiting preosteogenic cells from the central distracted tissue, become mineralized, and are rimmed by osteoblasts. After 6 weeks of retention, the trabeculae thickened, consisting of a mixture of lamellar and

woven bone. Remodeling and thickening of the trabeculae are achieved through bone resorption by osteoclasts and further bone formation by the osteoblasts.⁷ The remodeling process (without lengthening) produced mature lamellar bone.⁷

In conclusion, (1) the distraction force creates a pool of undifferentiated mesenchyme-like cells with osteogenic potential and triggers capillary formation; (2) a clear zonation can be observed during active lengthening; (3) new bone trabeculae begin to form between 5 and 10 days postdistraction, which soon become aligned with osteoblasts and continue to grow as long as distraction force is applied; (4) during the consolidation period, the trabeculae became thicker, with a mixture of lamellar and woven bone and gradually increased mineralization.

This characterization may help in any exogenous involvement with growth factors to improve bone quality.

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2B

Distraction Osteogenesis in Maxillary Deficiency Using Intraoral Devices

Adi Rachmiel and Dror Aizenbud

Primary cleft lip and palate repair done during infancy and early childhood improves the facial appearance, speech, and deglutition, but these early surgical interventions cause an impairment of maxillary growth, producing secondary deformities of the jaw and malocclusion.^{1,2} Ross showed that approximately 25% of patients with unilateral cleft lip and palate develop maxillary hypoplasia that will not respond to orthodontic treatment alone.² The hypoplastic maxilla is usually advanced later by Le Fort I osteotomy, with or without bone graft, to reestablish facial balance and occlusion.³⁻⁵ However, the maxilla in these patients is often difficult to mobilize because of the scarring from previous operations. In spite of improvements in surgical fixation, there is a greater tendency to relapse in cleft palate patients compared with non-cleft palate patients with maxillary hypoplasia.^{3,6,7}

Treatment of severe maxillary hypoplasia, especially in patients with an orofacial cleft, has been unstable when conventional Le Fort I maxillary advancement is used.

Distraction osteogenesis has been established as a predictable method for maxillary bone elongation, with generation of new bone in the distraction site, in both animal studies⁸⁻¹¹ and clinical cases.¹²⁻¹⁴

The purpose of this study is to present our experience in the treatment of maxillary deficiency in cleft palate patients using intraoral distraction devices and to present the clinical and cephalometric results in these patients.

Management and Surgical Technique

Ten patients, six with unilateral and four with bilateral cleft palate, ranging in age from 12 to 18 years, were treated. All had undergone primary lip and palate repair in infancy and early childhood and had previously treated by secondary bone grafting of the alveolus and maxilla between the ages of 8 and 11 years. They all had an antero-posterior maxillary hypoplasia with Class III malocclusion and a negative overjet, resulting in a concave profile (Figure 2B-1).

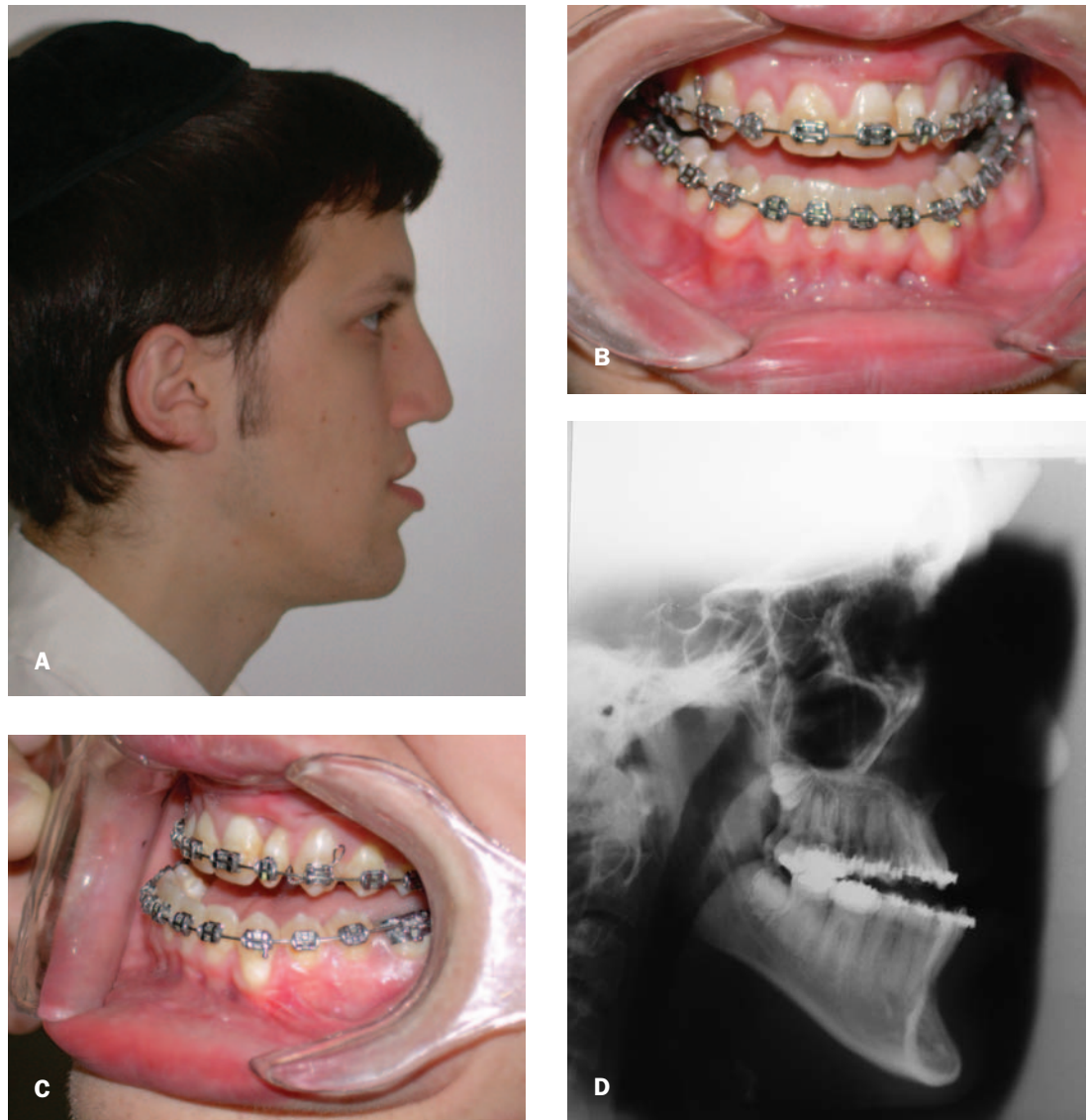


FIGURE 2B-1 A, Profile of a 17-year-old patient with maxillary deficiency and Class III malocclusion. B and C, The preoperative Class III malocclusion. D, Preoperative lateral cephalometric radiograph demonstrates the maxillary deficiency.

Lateral cephalograms were taken before and after distraction and compared with the lateral cephalograms taken after 1 year of follow-up. The preoperative cephalometric measurements, dental relationship, and soft tissue analysis revealed the anteroposterior maxillary hypoplasia.

The maxillary retrusion was manifested mainly by decreased SNA angle, reduced maxillary length (Co-A), and a negative overjet (Table 2B-1). Anteroposterior (sagittal) and vertical changes in hard and soft tissue and the occlusal changes were analyzed.

The cephalometric analysis included four sets of measurements:

- 1. SNA; maxillary length (Co-A)
- 2. SN-mandibular plane (MP); lower face/total face ratio (L/T)
- 3. Dental relations: upper 1 to SN (sella-nasion); overjet
- 4. Soft tissue: Gl'-Sn'-Pog' (glabella-subnasal-pogonion); NLA (nasolabial angle)

A circumferential horizontal incision was made in the maxillary vestibule above the attached mucosa, between the second molar region on both sides of the maxilla, exposing the lateral walls of the maxilla from the piriform aperture anteriorly to the pterygomaxillary junction posteriorly, including the two zygomatic buttresses. Different osteotomies may be performed according to the maxillary deficiency and the correction needed. The maxillary osteotomies may be (1) horizontal osteotomy, for forward distraction of the maxilla; (2) oblique osteotomy, for forward and downward distraction of the maxilla; and (3) step osteotomy, for children when the canine and premolar roots or buds are unerupted in a higher position in the maxilla (Figure 2B-2). A careful radiographic and clinical examination of the lateral maxillary wall was performed to plan the

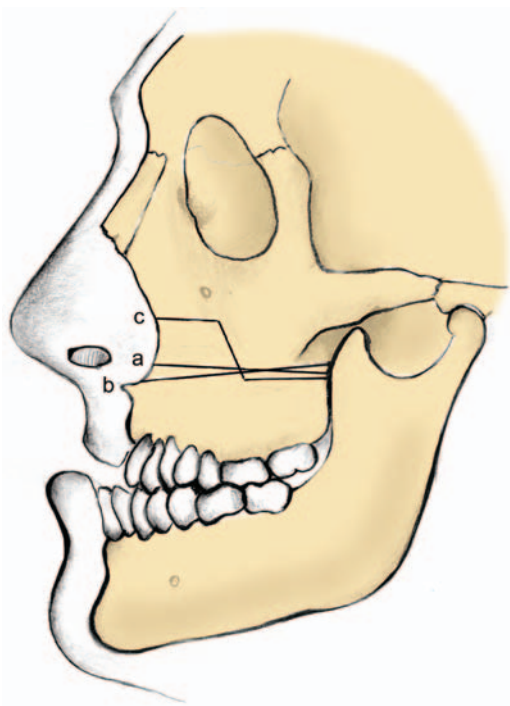


FIGURE 2B-2 Different Le Fort I osteotomies for maxillary distraction: A, horizontal; B, oblique; C, step osteotomy.

maxillary osteotomy so as not to damage the teeth roots. By using a reciprocating saw, an osteotomy was performed at least 8 mm above the teeth roots from the lateral piriform rim anteriorly toward the maxillary tuberosity posteriorly. A sharp curved osteotome was then driven medially and posteriorly into the pterygomaxillary suture to separate the maxillary tuberosity from the pterygoid plates to allow anterior movement of the maxilla. The medial wall of the maxillary sinus and the nasal septum were cut. In this manner, the maxilla was osteotomized at a Le Fort I level,

followed by mobilization. The anterior vector of the lengthening was determined, and two intraoral maxillary distractors (KLS Martin, Jacksonville, FL) were adapted on each side with an upper anchorage on the zygomatic buttresses, where the bone is thickest.¹⁵ The lower arm of the maxillary device was anchored along the lateral maxillary wall bellow the transverse osteotomy and above the tooth apexes using monocortical screws (Figure 2B-3). Forward advancement of the maxilla was achieved by turning the two distracted rods at a rate of 0.5 mm twice a day as was necessary until Class I occlusion with slight overcorrection was achieved. The maximum distracted length permitted by the device was 15 mm. After 8 weeks of retention, the two devices were removed using the same intraoral incisions.

Results

All 10 patients treated by intraoral distractors demonstrated marked advancements of the maxilla (Figure 2B-4A). After the gradual distraction, 8 weeks of consolidation ensured stable results of the advancements.

Five days of cefazolin 40 mg/kg/d was routinely used. All patients began routine oral hygiene and a soft diet 24 hours postoperatively and during the active distraction. No intermaxillary fixation or bone grafts were used. There was no surgical morbidity in any of the patients. There were no problems with bleeding or infection and no problems of dental injury. For some of the patients, during the distraction, elastics were placed to guide the vector of distraction to prevent an open bite.

The preoperative and post-treatment cephalometric measurements and the cephalometric changes are presented in Table 2B-1, with a long-term cephalometric evaluation that demonstrates stable results. All of the patients treated demonstrated marked forward advancement of the maxilla (Figure 2B-4B). Normalization of the sagittal maxillomandibular relationship was achieved. The maxillary movement was demonstrated by the increased SNA angle and the maxillary length (Co-A) (see Table 2B-1). The mean maxillary anterior movement measured by dental overjet was 11.6 mm, and the occlusion changed from Class III to Class I, requiring further final orthodontic adjustments. There was an associate increase in vertical dimension of the face owing to slight downward movement of the maxilla, resulting in a more posterior position of the mandible owing to clockwise rotation. The vertical changes were measured by increased SN-mandibular plane angle and increased lower facial height. There was associated improvement in facial convexity demonstrated by the increased Gl'-Sn'-Pog' angle. The nasolabial angle increased

Table 2B-1 Cephalometric Values before Distraction, Postdistraction, and after 1 Year of Follow-Up after Maxillary Advancement with Intraoral Distraction Devices (N = 10)			
Cephalometric Value	Predistraction	Postdistraction	After 1 yr
Skeletal maxillary			
SNA (°)	76.53	83.15	82.70
Maxillary length Co-A (mm)	77.25	88.40	83.90
Vertical relations			
SN-mandible plane (°)	33.5	34.14	34.10
Lower face height ratio (L/T) (%)	54.10	57.48	57.20
Dental relations			
Upper 1 to SN (°)	94.20	102.60	101.50
Overjet (mm)	-9.10	2.50	1.80
Soft tissue			
Gl'-Sn'-Pog' (°)	2.80	14.20	13.60
Nasolabial angle (°)	95.15	99.70	99.35



FIGURE 2B-3 Lateral cephalometric (A) and panoramic (B) radiographs demonstrate the two intraoral distraction devices.



FIGURE 2B-4 A, The profile at the end of treatment following removal of the device. B, The postoperative lateral cephalometric radiograph showing marked advancement of the maxilla.

owing to the maxillary support to the base of the nose, and there was greater esthetic balance between the nose and upper lip. After 1 year of follow-up, the clinical results were stable (Figure 2B-5, A–C). The cephalometric measurements concerning skeletal and dental relationships were compared after 1 year of follow-up and revealed

satisfactory stability (see Figure 2B-5D and Table 2B-1).

Discussion

In all of our patients, the forward distraction was performed after the secondary bone grafting took

place between 8 and 11 years of age. It is preferred to connect the distraction device to one intact segment of the maxilla and not two (in unilateral cleft) or three (in bilateral cleft) segments of bone so that better control of movement and better healing of bone were achieved. The results presented demonstrate that intraoral distraction devices can successfully lengthen the maxilla. There was a marked forward movement of the maxilla with correction of the negative overjet and some increase in the vertical dimension of the jaws owing to the associated slight downward movement of the maxilla. In maxillary distraction, we used three types of osteotomies: (1) horizontal osteotomy, for forward distraction of the maxilla; (2) oblique osteotomy, for forward and downward distraction; in cleft palate patients, usually the maxilla is hypoplastic in anteroposterior aspect and slightly vertical, and the osteotomy allows forward traction of the maxilla with slight vertical elongation; and (3) step osteotomy, in children with canine or premolar roots or buds in a higher position in the maxilla. The surgical procedures used for correction of maxillary deficiency in cleft palate patients include maxillary osteotomy, bone grafting, and stabilization with rigid fixation.^{3,5–7} However, the dense scar tissue present in most cleft palate patients may account for some relapse after orthognathic surgery.^{3,6,7}

Obwegeser used bone grafts in the posterior gap between the maxillary tuberosity and the pterygoid plates to prevent relapse after maxillary advancement.⁴ Other authors used miniplate fixation along with interpositional bone grafting to improve stability.^{1,6,7,16,17} In maxillary advancement of cleft palate patients, the primary objective in using a bone graft is to promote bony healing and thus create stability.

A disadvantage of autogenous bone grafting is the potential donor-site morbidity.¹⁸ Experimental studies have demonstrated formation of mature lamellar bone lengthening by distraction osteogenesis.^{11,19} The newly formed bone can provide good support and, thus, will contribute to stability. However, in our experimental study, the maxilla was advanced 40 mm by distraction osteogenesis, with only 7% relapse during 1 year of follow-up.⁹

In another study, cephalometric evaluation of 14 mm maxillary advancement using internal distractors demonstrated stable results 1 year after removal of the distractors.²⁰ Kusnoto and colleagues in a radiographic evaluation performed by tomogram technique found a pattern of bone formation in the pterygoid region after maxillary distraction.²¹ The bone trabeculae could be seen 6 weeks after active distraction. Therefore, it is important to have a long period of consolidation for stable results to prevent relapse. Distraction osteogenesis can provide an alternative method for maxillary advancement in patients with a tendency to relapse, such as cleft palate



FIGURE 2B-5 A, The profile after 1 year. B and C, The postoperative occlusion at the end of orthodontic treatment. D, The cephalometric radiograph after 1 year demonstrates stable results.

patients, due to the new bone formation during distraction.

In our study, the fixation of the distractors was on the zygomatic bones for good anchorage. Also, Cheung and colleagues confirmed that the zygomatic bones and paranasal area are the thickest for fixation of internal maxillary distractors and the holding strength of the screws in these regions correlates with the cortical bone thickness.¹⁵ Unstable devices may even cause failure of distraction and are commonly associated with fibrous union or pseudoarthrosis in the distraction gap. In intraoral devices, the vector of elongation is determined when placing the device and cannot be changed during distraction. Therefore, the device stability is very important, particularly for the intraoral devices.

The main advantage of the maxillary internal devices is that the device is located under the soft tissue and is socially preferred by the patients. The disadvantages are as follows: (1) the devices cannot perform three-dimensional corrections; (2) less control of the vector of lengthening in relation to the extraoral devices; in some patients, additional elastics were placed to guide the final vector of lengthening and proper occlusion; (3) limited distraction length; and (4) a second operation for removal is required. However, with the extraoral devices, there is better control in the vector of lengthening; the vector can be changed during lengthening, with longer distraction length than the intraoral distractors, and the removal of the device is performed simply by unscrewing the fixation screws.

Another advantage of maxillary distraction is the positive soft tissue changes by increasing the nasal projection, normalizing the nasolabial angle, and making the upper lip more prominent.^{22,23} The concave facial profile became convex. The nose in cleft palate patients shows marked retrusion and retroclined configuration. It is known that the nasal movement in cleft palate patients after Le Fort I advancement is 1:3.²⁴ However, in cleft palate patients with a maxillary distraction device, the ratio was 1:2.²² Also, in the present study in cleft palate patients, the ratio of nasal movement is 1:2. When working with patients in a period of growth, we recommend slight overadvancement of the maxilla with follow-up after maxillary growth.

Indications for maxillary distraction are as follows: (1) moderate and severe retrusion that needs large advancement in special cleft lip and palate patients; (2) forward and downward lengthening of the maxilla; there is no need for intermediate bone graft; and (3) growing patients.

The results of this study showed that the maxilla in young cleft palate patients can be lengthened successfully using intraoral distraction devices with long-term stability. Further growth of the maxilla should be studied in growing patients.

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Ambulatory Anesthesia

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The introduction of modern anesthetics, advanced methods of airway management, and sophisticated monitoring systems has simplified and made anesthesia extremely safe for the oral and maxillofacial surgery patient. Up until a decade ago, most major surgical procedures were performed on an inpatient basis. The evolution of ambulatory surgery has taken several decades, and surgeons of various specialties have often greeted these changes with skepticism. We have established general guidelines for the appropriateness of procedures performed on the oral and maxillofacial region in an ambulatory setting¹ (Table 3-1).

In the past, a major concern with many oral and maxillofacial procedures has been airway management. Concurrent with advances in ambulatory anesthesia, there have been advances in surgical technique. When orthognathic surgery was in its infancy, patients were routinely kept in maxillomandibular fixation (MMF) and observed postoperatively in intensive care units (ICUs). The widespread availability of rigid fixation has diminished the need for MMF and ICU management. This concept is particularly appealing with the increasing popularity of rigid internal and external distraction systems. With few exceptions, all routine oral and maxillofacial procedures can be safely performed on an ambulatory basis¹ (Table 3-2).

Preoperative Evaluation

A significant percentage of the potential complications in the administration and management

Table 3-2 Acceptable Ambulatory Oral and Maxillofacial Procedures

Dentoalveolar surgery
Preprosthetic surgery
Dental implant surgery
Incision and drainage of single-space odontogenic infections
Reduction of facial fractures*
Closure of orofacial lacerations
Temporomandibular joint surgery
Orthognathic surgery[†]
Distraction osteogenesis (Le Fort I or mandible)

*Maxillomandibular fixation (MMF) for closed reduction of mandibular fractures unassociated with gross edema and/or bleeding.

[†]Restricted to single jaw surgery that is unlikely to need MMF; routine intraoral vertical ramus osteotomies generally acceptable.

of anesthesia can be avoided by careful preoperative evaluation and planning. The preoperative evaluation of a patient may be divided into three parts: (1) medical history, (2) physical evaluation, and (3) required consultation and necessary laboratory or imaging studies.² The preoperative interview with the patient and family fulfills three important functions in ambulatory surgery: (1) acquisition of pertinent information about the patient's medical and surgical history, and physical examination findings, (2) obtaining informed consent, and (3) educating the patient about anesthesia in order to reduce anxiety.

Oral and maxillofacial procedures encroach on the airway, thereby creating a situation that is challenging for both the surgeon and the anesthesiologist. The preoperative visit is of paramount importance for the anesthesiologist to directly observe and evaluate the patient's facial deformity. A simple examination can determine if the airway will be difficult, and an anesthetic plan can be formulated including the type and position of the endotracheal tube, optimal placement of intravenous lines, and location of the anesthesia machine. Of particular importance in maxillofacial anesthesia are a discussion of hypotensive techniques and the duration of postoperative endotracheal and/or nasogastric tube placement relative to MMF.³ When obtaining informed consent, such possible after effects as mild pharyngitis and epistaxis can also be explained.

Before general anesthesia and oral or nasotracheal intubation are contemplated, the airway must be evaluated by both the surgeon and the anesthesiologist. A significantly deviated nasal septum, edematous nasal mucosa, prominent turbinates, enlarged adenoids, and/or hypertrophied tonsils can contribute to difficulty during nasotracheal intubation and to postoperative airway problems. These factors may preclude the ability to safely manage the patient in an ambulatory setting. Even though a patient has an adequate nasal airway preoperatively, the superior movement of the nasal floor produced by some orthognathic procedures or by postoperative mucosal edema reduces the size of the nasal airway, an important consideration if maxillary surgery is planned. If the patient is an obligate mouth breather, the nasal airway could be significantly improved by turbinectomies during the surgical procedure.

Four criteria have been established in the evaluation of the airway for ease of intubation in maxillofacial surgery.⁴

1. *Mobility of the neck.* The neck is evaluated clinically by asking the patient to touch the chin to the anterior chest and each shoulder, evaluating the patient and any noted limitations during the flexion/extension of the head.
2. *Position of the trachea relative to the mandible.* If the distance from the thyroid cartilage to the anterior chin is less than 6.5 cm, the larynx is considered "anterior" and may present a visualization problem during intubation. Clinically, the acceptable position is approximated by 4 fingerbreadths between the thyroid cartilage and the anterior chin (Figure 3-1). Problems arise in orthognathic surgery patients with severe mandibular retrognathia.
3. *Ability of the patient to open the mouth.* The range of mouth opening in healthy adults is at least 3.6 cm, or at least 3 fingerbreadths positioned vertically between the incisor teeth (Figure 3-2). Problems are found in those individuals with three major types of anatomic problems: (1) those with preexisting internal derangements or degenerative disease in the temporomandibular joint

Table 3-1 Guidelines for Ambulatory Oral and Maxillofacial Surgical Procedures

Associated with minimal blood loss (< 300 cc)
No airway compromise*
Postoperative pain managed easily
Postoperative nausea and vomiting easily managed
Postoperative fluids tolerated orally
Postoperative care manageable by family and friends

*No need for maxillomandibular fixation (MMF) anticipated. Excludes routine intraoral vertical ramus osteotomies with MMF. No pharyngeal edema anticipated.



FIGURE 3-1 Assessment of tracheal position relative to the chin. A minimum distance of 4 fingerbreadths is generally considered adequate to facilitate direct exposure to the trachea.



FIGURE 3-2 Assessment of interincisal opening. A distance of 3 fingerbreadths is considered adequate to visualize direct exposure of the trachea.

(TMJ), (2) those with mandibular and/or zygomatic fractures preventing adequate mandibular opening, and (3) those with congenital or acquired ankylosis of the TMJ.

4. *Structures visualized when the patient opens the mouth and vocalizes “aahh. . .”* During the examination, one should be able to see the uvula and parapharyngeal structures. If only the soft palate and tongue are seen, and no delineation appears between the tongue and the soft palate, then one may expect a more difficult intubation, particularly if direct laryngoscopy is needed. A scoring system has been advocated to evaluate the ease with which oropharyngeal structures are visualized as a correlation to ease of intubation⁵ (Figure 3-3). Problems in visualizing the uvula should be anticipated in those patients undergoing uvulopalatopharyngoplasties and/or orthognathic surgery for the management of obstructive sleep apnea.

If these criteria are all normal, one can feel comfortable in anesthetizing the patient prior to tracheal intubation. If any of the above criteria are

not met, then either fiberoptic or sedated-awake nasal intubation should be considered, in a hospital setting, prior to fully anesthetizing the patient. The fiberoptic or sedated-awake nasal intubation are planned procedures requiring adequate

preparation and should not be used immediately after failed attempts at direct or blind nasal intubation.⁶

Many patients with dentofacial and craniofacial anomalies may have partial airway obstruction.

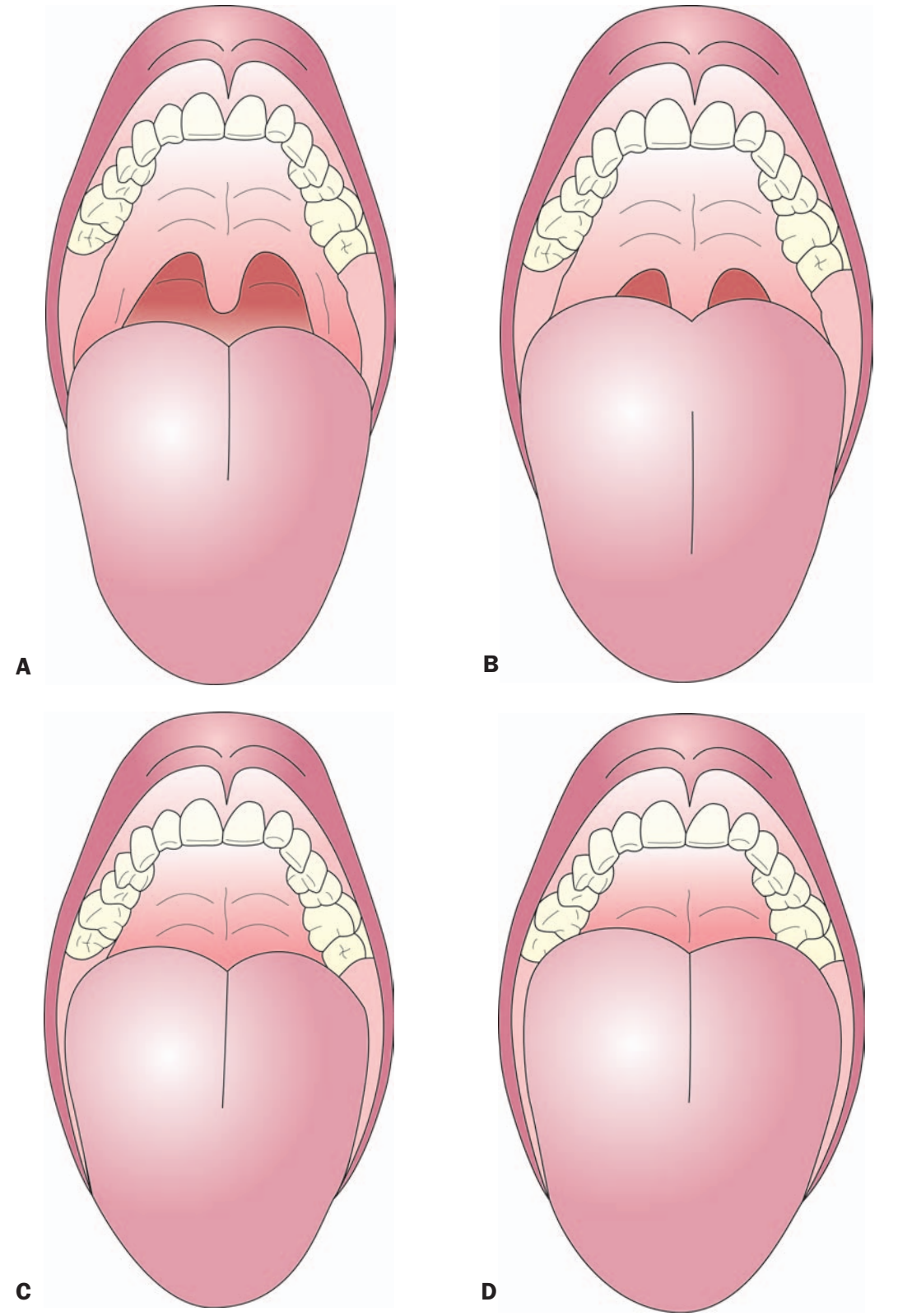


FIGURE 3-3 The four Mallampati (MP) classes are used to evaluate the ease of intubation based upon visibility of oropharyngeal structures. A, MP 1: Faucial pillars, soft palate, and uvula are visualized. B, MP 2: Faucial pillars and soft palate are visualized, but the tip of the uvula is obscured by the base of the tongue. C, MP 3: Only soft palate and base of uvula is visualized. D, MP 4: The soft palate is not visible at all.

tion, which may present as an abnormal sleep pattern. Patients with Apert's or Crouzon's syndromes develop maxillary hypoplasia, leading to stenosis of the nasal cavity and nasopharynx. Passage of a nasoendotracheal tube in these patients may be quite difficult. Furthermore, orthognathic superior maxillary repositioning may cause patients with adequate preoperative airways to have some postoperative airway problems secondary to blood clot development within the sinuses, trauma to the nasal mucosa, or decreased nasal airway volume.⁷ Patients with a cleft palate who have had prior palatoplasties or pharyngeal flap procedures should be evaluated by indirect pharyngoscopy or by direct nasopharyngoscopy to determine the ease with which the endotracheal tube can be passed without injury to the flap. As previously described, mandibular function must be evaluated for potential difficulty of intubation. A few patients with significant dentofacial deformities will be difficult or impossible to intubate because of abnormalities of the mandible. Many of these patients who would have previously required tracheotomies can be safely managed with fiberoptic or sedated-awake intubations. It is noteworthy that up to 50% of patients with Goldenhar's syndrome possess cervical spine abnormalities, including cervical spine fusion, which may lead to difficulty in visualizing the patient's vocal cords. Additionally, a significant number of craniosynostosis patients have associated cardiovascular abnormalities. These patients should be seen preoperatively by a cardiologist to help optimize medical management and determine the need for prophylactic antibiotics.

Preoperative Laboratory Studies

Preoperative screening of healthy patients who are to undergo ambulatory oral and maxillofacial surgery should involve the acquisition of any needed laboratory tests. No amount of laboratory testing can replace a good history and physical examination, and the laboratory tests ordered should be guided by pertinent findings in your examination. Many ambulatory surgery centers continue to obtain substantial batteries of preoperative laboratory studies for patients. False-positives on laboratory screening often lead to increased patient anxiety, increased operating room delays and costs, and may lead to more invasive diagnostic tests and therapies that can actually injure patients. An acceptable standard of screening laboratory studies for asymptomatic healthy outpatients may be adapted to ambulatory maxillofacial surgery. We recommend that preexisting medical conditions be under optimal management for a period of at least 3 months prior to elective surgery. In general, no laboratory studies are obtained for healthy males less than 50 years of age, and only a hematocrit for healthy

females less than 50 years of age, unless determined necessary by physical examination.

Unsafe Patients for Ambulatory Surgery

It is quite difficult to reliably categorize the inappropriate ambulatory oral and maxillofacial surgery patient. One must take into account the outpatient's physical, intellectual, and psychological status. Ambulatory patients must have an escort who is a responsible adult and can provide proper home care for the patient after discharge. We have established several groups of patients who may be inappropriate candidates for ambulatory oral and maxillofacial surgery (Table 3-3). From a surgical standpoint, those patients undergoing bimaxillary surgery, upper level Le Fort procedures (Le Fort II or III osteotomy or distraction), and/or procedures associated with excessive blood loss (ie, multiple osteotomies) should not be treated in an ambulatory setting.

Anesthetic Techniques

Preoperative Preparation

Preoperative fasting is intended to help reduce the risk of tracheal aspiration during the induction period. In recent years, traditional fasting guidelines have been a topic of much debate. A small amount of clear fluid ingested 2 hours prior to surgery may actually facilitate gastric emptying. For oral and maxillofacial surgery patients older than 5 years of age undergoing sedation or general anesthesia, it is still desirable to have no clear liquids or solid food after midnight, given the potential for MMF in the postoperative period. Children 6 months to 5 years of age may have clear liquids 2 hours prior

to anesthesia and no solid foods after midnight. The following conditions are considered to place the patient at increased risk for pulmonary aspiration of gastric contents during anesthesia: hiatal hernia, gastric or duodenal ulcers, esophageal reflux, diabetes, or obesity. The routine prophylaxis against acid aspiration remains an area of intense controversy in ambulatory anesthesia. In ambulatory oral and maxillofacial surgery patients who are "at risk" for aspiration, particularly in cases not involving endotracheal intubation, a histamine H₂ receptor blocker (ie, ranitidine) is given 1 to 2 hours prior to induction.

Operations on the head and neck often contribute to nausea and vomiting in the postoperative period, and this side effect is particularly disturbing in outpatients as it can delay discharge and/or result in unexpected hospital admissions. Surgery of the maxilla, mandible, and sinuses may result in the passive swallowing of blood, which contributes to postoperative nausea and vomiting (PONV). Ondansetron provides excellent antiemetic activity without the sedative and dysphoric side effects inherent with older antiemetics. In susceptible patients, ondansetron is given in the recovery room in a dose of 0.15 mg/kg intravenously over 15 minutes, and it is rare that a repeat dose is necessary.

Nasal Preparation

Most surgical procedures on the maxilla and/or mandible mandate a nasotracheal intubation. In patients undergoing nasal intubation, oxymetazoline hydrochloride or NeoSynephrine spray is routinely administered intranasally (eg, three puffs in each nostril prior to induction). Both nasal sprays are used as quick-onset decongestants. As sympathomimetic amines, they stimulate the α₁-adrenergic receptors of the nasal vascular smooth muscle, thereby shrinking the mucous membranes and allowing a less traumatic intubation. Placement of a nasopharyngeal airway follows nasal preparation in the early stages of general anesthesia induction. The nasopharyngeal airway serves three purposes: (1) diagnosis of nasal obstruction or narrowing, (2) dilation of the nares, and (3) dulling of the nares (viz, the three D's). Thus, the nasopharyngeal airway is essential prior to all elective nasal intubations to diagnose the more patent nares, and to dilate and act as a vehicle for the application of lubricants or topical anesthetics.

Endotracheal Tube Preparation

A nasal intubation is desirable for most oral and maxillofacial procedures because it provides an unobstructed visualization of the orofacial structures. The proper tracheal tube (TT) should be a nasal Ring Adair Elwyn (RAE)-type tube, which is sized according to the size of the patient.

Table 3-3 Inappropriate Ambulatory Oral and Maxillofacial Patients

Medical
Unstable ASA physical status (III or IV)
Susceptible to malignant hyperthermia
Receiving monoamine oxidase inhibitor therapy
Morbidly obese patient and history of sleep apnea
Surgical
Maxillomandibular fixation required*
Postoperative pharyngeal edema
Excessive blood loss (> 300 cc)
Upper level Le Fort osteotomy and distraction†
Psychosocial
Unwilling or unable to participate
No responsible adult to monitor the patient after surgery

ASA = American Society of Anesthesiologists.
*Intraoral vertical ramus osteotomies are acceptable in select patients.
†Le Fort II or Le Fort III.

For most adults, a 6.5 mm TT for females and a 7.0 mm TT for males are the appropriate sizes for nasal intubation. On occasion, a nasal RAE tube is unavailable or may not be of sufficient length, and alternatives or tube customization is thus called for. A detailed review of the steps involved in nasotracheal intubation, including techniques in customizing and stabilizing nasal tubes for maxillofacial anesthesia, are discussed in the selected references by the senior author (GEG). It is helpful to place the distal third of the nasotracheal tube in hot water for 2 to 3 minutes to soften the tip. This step helps to avoid traumatic injuries to the nasal mucosa and minimizes iatrogenic epistaxis.

Preoperative Medications

Benzodiazepines (diazepam, midazolam, lorazepam) are rarely used as induction agents in the ambulatory setting because of the prolonged recovery time. On the other hand, they remain the most widely used drugs for premedication and deep sedation. The use of midazolam (Versed) for intravenous sedation in general dental practice provides a more rapid recovery, more effective and profound amnesia, and less venous sequelae when compared with diazepam. For preoperative sedation, intravenous (IV) midazolam (0.05 to 0.075 mg/kg) is administered in divided doses until a predetermined clinical end point is achieved (ie, slurred speech). Constant monitoring equipment must be attached to the patient during the administration of the intravenous sedative and analgesic agents. Opioid analgesics are given intravenously as a preinduction agent to permit a lighter level of anesthesia for maintenance, contributing to a more rapid emergence and a smooth pain-free awakening and recovery. For the ambulatory patient, the ideal opioid has a rapid onset, short duration of action, potent analgesic effect, minimal effect on vital signs, and does not delay discharge to home. The most popular opioid in the ambulatory surgery setting is the potent, rapid, and short-acting narcotic analgesic fentanyl. Fentanyl (1 to 3 µg/kg IV) is administered 3 to 5 minutes prior to intubation. Fentanyl effectively attenuates the cardiostimulatory response to laryngoscopy and endotracheal intubation. With the patient adequately sedated, the induction phase may be approached in a calm, nonthreatening manner.

General Anesthesia

Induction of general anesthesia is usually accomplished with a rapid-acting intravenous anesthetic. Methohexital (1 mg/kg) was, until the last decade, the most commonly used ultrashort-acting barbiturate in ambulatory oral and maxillofacial surgery. Methohexital is associated with slightly shorter awakening and recovery times

when compared with thiopental. The disadvantages of methohexital include involuntary muscle movements, hiccups, and occasional pain on injection. However, methohexital enjoyed great success in ambulatory oral and maxillofacial surgery until the introduction of propofol. Propofol has replaced thiopental as the best induction and maintenance agent for the ambulatory patient. Propofol produces less residual postoperative sedation and psychomotor impairment than the barbiturates, as well as a lower incidence of nausea and vomiting. For induction of general anesthesia in ambulatory oral and maxillofacial surgery, propofol (1 to 2 mg/kg) has become a more logical alternative to methohexital. For the pediatric patient undergoing ambulatory oral and maxillofacial surgery, the induction of general anesthesia is most commonly accomplished via mask inhalation with sevoflurane, and an intravenous line is then established. Often, the pediatric outpatient benefits from preinduction sedation with midazolam (0.50 to 0.75 mg/kg, per orally) in the cooperative child, or ketamine (4 to 5 mg/kg) intramuscularly (IM) combined with glycopyrrolate (0.2 mg IM) in the uncooperative patient.

Muscle relaxants are employed during the induction of general anesthesia to facilitate tracheal intubation, allowing a lighter level of anesthesia to be maintained, and to treat emergency laryngospasm. The depolarizing muscle relaxant succinylcholine (1 to 1.5 mg/kg IV) is still the most popular relaxant for ambulatory oral and maxillofacial surgery in spite of its well-known ability to trigger malignant hyperthermia and postoperative myalgias. The availability of short- and intermediate-acting neuromuscular blocking drugs (eg, mivacurium, vecuronium, rocuronium) has resulted in decreased use of succinylcholine in ambulatory anesthesia. An intubating dose of these nondepolarizing muscle relaxants should be preceded by a small priming dose to enhance the onset (to complete blockade) of these compounds.

Controversy persists concerning the optimal technique for maintenance of anesthesia during ambulatory surgery. A volatile anesthetic in combination with nitrous oxide (60 to 70%) remains the most popular technique for maintenance of anesthesia in ambulatory oral and maxillofacial surgery. The use of nitrous oxide as a maintenance agent significantly reduces the volatile anesthetic requirement. One should remember the disadvantages associated with nitrous oxide, namely diffusion hypoxia and increased pressures in nitrogen-containing body spaces, as well as increased PONV. Studies, however, have failed to establish a definite correlation between the incidence of PONV and the use of nitrous oxide. In general, the most commonly used volatile agents are considered superior to intravenous agents for

maintenance during ambulatory anesthesia, because changes in the depth of anesthesia can be made more rapidly. All of the commonly used inhalation agents possess similar pharmacologic activities in healthy patients, and are less arrhythmogenic than halothane. Owing to the excellent vascular supply of the maxillofacial region, it is often necessary to supplement general and sedative techniques with epinephrine-containing local anesthetic injections to aid in hemostasis. In doing so, one should limit exogenous epinephrine to 1 µg/kg in the presence of halothane; however, the maximum dose of epinephrine-containing solutions injected during anesthesia with isoflurane, sevoflurane, or desflurane is 2 to 4 µg/kg. Alternatively, an intravenous infusion of propofol in combination with nitrous oxide (70%) may be titrated in a fashion similar to that of conventional inhalational agents. When one compares variable-rate infusions of propofol (4 to 8 mg/min) with methohexital (3 to 6 mg/min) for ambulatory anesthesia, fewer side effects and earlier discharge are experienced with propofol-based anesthetic techniques.

Conscious Sedation with Local Anesthesia

The four primary objectives of conscious sedation include 1) relief of anxiety, 2) amnesia, 3) adequate sedation with minimal risk, and 4) relief from pain or discomfort. All oral and maxillofacial procedures performed under sedation require the injection of local anesthetics to supplement analgesia. The use of conscious sedation techniques has been popularized by oral and maxillofacial surgeons to help alleviate the discomfort associated with the injection of local anesthetics and to provide amnesia. The most popular techniques for sedation involve the use of combinations of benzodiazepines, opioid analgesics, and sedative-hypnotics. The most widely used sedative combination in oral and maxillofacial surgery consists of midazolam and fentanyl. Following the establishment of intravenous access, the patient is sedated with midazolam using small carefully titrated doses to achieve the desired clinical end point (slurred speech). Experience has shown that the average dose of midazolam is 2 to 5 mg (0.05 to 0.075 mg/kg) to achieve the desired clinical effect. Subsequently, incremental doses of fentanyl 25 to 50 µg are administered intravenously for analgesia to a maximum dose of 150 µg (1 to 2 µg/kg) per sedation. Additionally, during the peri-injection period, propofol (10 to 30 mg) may be administered in bolus form for additional sedation with a predictably rapid recovery. Alternatively, the use of carefully titrated continuous intravenous infusions of propofol (2 to 4 mg/min) produces a stable level of sedation during local anesthesia.

Evaluation of arterial blood gas levels after the administration of a benzodiazepine with or without fentanyl for sedation during ambulatory oral and maxillofacial surgery found that the addition of a potent opioid analgesic (fentanyl) caused significant hypoxemia in healthy outpatients when administered after the benzodiazepine (midazolam). Therefore, supplemental oxygen is always recommended when this combination is used during local anesthesia. To avoid the apparent synergism between midazolam and fentanyl with respect to ventilatory depression, techniques that have a lower risk of ventilatory depression (ie, midazolam–ketamine or propofol–ketamine) are becoming more popular. The obvious advantage of ketamine-induced analgesia is the lack of significant respiratory depression when combined with midazolam. When using the midazolam–ketamine technique for ambulatory oral and maxillofacial surgery, the patient is first sedated with midazolam (0.05 to 0.75 mg/kg) over 3 to 5 minutes, followed by ketamine (0.25 to 0.5 mg/kg). Since ketamine causes increased oral secretions, an antisialagogue (glycopyrrolate 0.2 mg IV) should be administered to reduce the incidence of coughing or laryngospasm. The use of midazolam with ketamine decreases postoperative emergence delirium.

Postanesthesia Management

The current trend in pain management after ambulatory oral and maxillofacial surgery involves the use of a long-acting local anesthetic infiltrated at the conclusion of the procedure to provide prolonged analgesia and the use of oral opioid

and nonopioid analgesics to treat pain after discharge from the ambulatory facility. Most oral and maxillofacial surgical procedures lend themselves to local anesthetic nerve blockade for the purpose of postoperative pain relief. The anesthetic most commonly used is bupivacaine (0.25% with 1:200,000 epinephrine), which may produce postoperative analgesia for 8 to 12 hours. The use of local anesthetics appears to lessen the need for conventional analgesics in the postoperative period, thereby allowing for an earlier discharge. Oral analgesics, prescribed as take-home medications, may be administered in the recovery room once the patient has tolerated oral fluids. The use of opioid analgesics (eg, morphine, meperidine, fentanyl) has diminished in ambulatory oral and maxillofacial surgery with the increased use of nonsteroidal antiinflammatory drugs (NSAIDs). Ketorolac (30 to 60 mg IM) has shown analgesic efficacy equal to morphine (5 to 12 mg IM) or meperidine (50 to 100 mg IM). Use of ketorolac at the end of the surgical procedure has the advantage of producing no respiratory depression or sedation in the early postoperative period. Ketorolac (30 mg IM) has been studied for postoperative pain control following dental extractions and found to provide superior analgesia following third molar extractions compared with meperidine (50 to 100 mg IM).

Nausea and vomiting are among the most troublesome problems occurring in the postoperative period. For patients who get nauseous during recovery, ondansetron (10 mg or 0.15 mg/kg) administered intravenously has proven to be highly effective in controlling nausea and vomiting without producing the sedative side effects inherent in other antiemetics.

Summary

Ambulatory anesthesia has always been a critical component of the effective practice of oral and maxillofacial surgery. The surgeon and anesthesiologist must combine their efforts to optimize the ambulatory surgical experience for the patient and family. Appropriate patient selection is the first principle, followed by attention to monitoring standards as well as a thorough knowledge of the pharmacology of the commonly used anesthetic drugs. With the surgical advances in fixation and distraction techniques, the list of acceptable ambulatory oral and maxillofacial surgical procedures is expected to continue to grow in the near future.

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4A

Surgery Center Accreditation

Joe Niamtu III

The field of orthognathic surgery puts the “maxillofacial” in oral and maxillofacial surgery (OMS). Prior to this, oral surgeons were still among the best-trained head and neck surgeons, with an amazing scope, but when we began performing orthognathic surgery, the public and the competitors stood up and took notice. Orthognathic surgery is a unique service that our profession has dominated for decades.

The past decade has brought about many changes that have negatively affected the prevalence of orthognathic procedures. Unfortunately, these factors have nothing to do with the actual need for the procedure or the desire of our profession to perform it. These factors are largely insurance related, and it has gotten to the point where many experienced surgeons have abandoned orthognathic surgery because of the low pay, high liability, and intensity of work-up. This author feels that this will shift and that patients

will pay for what they view as necessary procedures. Very few patients balk at spending \$5,000 to \$7,000 (US) for orthodontics, breast implants, or wide-screen televisions. Our challenge is to make orthognathic surgery safe and affordable for patients and referring specialists. This author and his partners have pursued this mechanism by incorporating an Accreditation Association for Ambulatory Health Care (AAAHC) surgery center in our offices (Figures 4-1 and 4-2).

There are many advantages in having an accredited office and surgery center. These include improved patient care, safety, convenience, ability to bill for facility fees, and marketing advantage. Most oromaxillofacial surgeons are familiar with the accreditation process, but are intimidated and hesitant because of lack of understanding of the process. I, like others, once thought accreditation had to do with the physical facility.

I thought that I had to literally build a “small hospital” in my office and this misinformation kept me from proceeding. In reality, the accreditation process is much more about governance than physical plant. In effect, having an accredited facility is like practicing with Mother looking over your shoulder. It forces you to “do the right thing.” Accreditation requires the office and staff to address all common issues of patient care from sign in to sign out. It requires policies for most things that we all take for granted. It also requires the practice to perform such tasks as peer review, chart review, and efficiency studies. Although this seems distasteful to the average busy practitioner, it really does provide excellent and important feedback on safety, patient care, and efficiency. These studies may include patient care parameters such as the prevalence of postoperative nausea and vomiting, or more clerical topics such as average waiting times for new patients.

Practicing in an accredited facility is similar to having one’s own hospital, in terms of requiring specific policies, equipment, staff, medications, and the like (Figures 4-3 and 4-4). It may require the surgeon to dictate operative reports, perform more sophisticated drug counts, have emergency power back-up, and perform other cross-checks. Although many private practitioners cringe at such “extra work,” I have found one thing to be true. All of the doctors that I know personally have expressed that the accreditation process was not an easy one, but it was the best thing they had ever done. It has made them better



FIGURE 4-1 The author’s office and surgery center.



FIGURE 4-2 The main operatory of the office.



FIGURE 4-3 A back-up power supply was one piece of equipment required for accreditation.

doctors, made their offices safer and more efficient, provided a marketing advantage, and put OMS on the highest possible level.

Going solo through the accreditation process is a task of awesome proportion, as is fishing in

the ocean without a guide. With a guide, the fisherman can go directly to a productive area with known baits and techniques and save a lifetime of frustration. The same thing is to be said about an accreditation consultant. There are well-recognized companies that serve as coaches to greatly simplify the accreditation process. Using a consultant can save the surgeon and staff thousands of hours and thousands of dollars. The consultants assist the office in every step of the process and even perform a mock office accreditation survey. When our offices underwent professional accreditation consultation, the fee was approximately \$5,000 (US). In retrospect, it was some of the best money we had spent in the 22 years that we have been in business!

My worst fear was that we would have to purchase tens of thousands of dollars of “equipment.” In actuality, we did purchase an emergency back-up system for approximately \$3,000 (US), some lighted exit signs, a few fire extinguishers, and a label maker. The biggest changes were, as mentioned above, in terms of policies. We were required to draft or improve such things as patient confidentiality issues, hospital transfer policies, and needle stick and emergency policies. We had to develop credentialing policies similar to the

hospital, and each of my partners had to “apply for specific privileges.” We needed regular inspections by the local fire marshal and we needed to keep track of such mundane things as operating room (OR) schedules and practice marketing materials.

Since my partners and I had been steadily getting rejections for orthognathic surgery procedures, we wanted to make the process simple and affordable for surgical orthodontic patients without insurance coverage. This took a little thinking and reasoning. It all occurred about the time that I personally limited my OMS practice to only cosmetic facial surgery procedures. We saw that people (even those of average income) had no problem paying \$5,000 to \$12,000 (US) surgical fees for face-lifts and other cosmetic facial procedures. As most of us know, most people will pay cash for what they perceive as value to their life or health. The limiting factors with traditional orthognathic surgery was the hospital fees that could reach \$30,000 (US) and the surgeons fees that unfortunately are a thing of the past. It is well known that women readily pay \$5,000 to \$7,000 (US) for breast implants. Some merely write a check and some bring in “cookie jar” money, but thousands of women do it yearly. We wish that we could bill for orthognathic surgery like we did 20 years ago, but we also wish that gasoline was 75 cents (US) a gallon. We have attempted to provide a fair package for the patient requiring orthognathic surgery. We charge \$5,000 (US) per arch plus the anesthesiologist’s fee. There are some limitations when performing orthognathic surgery in the office. We find that single-arch surgeries are performed more commonly than those for double arch, although my partners have performed concomitant upper and lower osteotomies. We probably tend to be more conservative than with hospital patients, but it has not been a significant problem. On occasion, we will recover patients on a 23-hour basis with a staff registered nurse. Having the patient stay overnight with a nurse and on monitors has proven to be a safe and effective recovery strategy. Some patients choose to use a private duty nurse at their home, which is also a huge convenience and safety precaution. In Virginia, this costs the patient about \$300 (US).

We have used our surgery center and the ability to perform convenient, safe, and affordable orthognathic surgery as a marketing advantage with referring dentists and orthodontists as well as with the public.

In terms of accreditation agencies, multiple choices exist. The AAAHC is probably the most popular organization for outpatient office accreditation. The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) is the main accrediting body of hospitals but also certifies outpatient centers. The American Association for



FIGURE 4-4 Dantrolene, a medication that most oromaxillofacial surgery offices do not have, is required for accreditation if general anesthesia is used in the office.

Accreditation of Ambulatory Surgery Centers (AAAASC) is another accrediting body that, in this author's understanding, is comprised of plastic surgery offices for plastic surgeons. There are pros and cons of each individual accrediting body. The AAAHC is so popular that many patients recognize it. The JCAHO is the same body that accredits hospitals and there is something to be said about that statement in terms of understanding and marketing. Regardless of the accrediting body, it is the act of accreditation that makes one better.

In general, the time involved with getting accredited is beyond the available time commitment of most doctors. This means that one needs at least two extremely reliable, motivated, and willing staff members to head the team. Although every employee and doctor will be involved in some way, the team leaders are literally on the front line. I recommend that one of these persons be a registered nurse, as much of the accreditation process is similar to other health care facilities, and nurses simply understand it better and have been through similar situations. In reality, the doctor merely needs to serve as a supervisor and be informed of major changes and be familiar with basic policy. As stated above, having a reputable consultant literally saves thousands of dollars and hundreds of hours.

When changing gears from an office operatory to an accredited outpatient surgery center, there are things that are significantly different and must be addressed. Being accredited does not somehow transform your office into another place. In fact, there will hopefully be minimal changes of your physical plant—you will merely be doing things better, more efficiently, and safer. Since most oromaxillofacial surgeons perform short procedures on young healthy patients, the entire process must be rethought when considering orthognathic or cosmetic surgery. With orthognathic surgery, the main challenge is the anesthesia. These patients require intubated general anesthesia and the procedure can sometimes result in significant blood loss. Fluid management and postanesthesia recovery are other factors that require close care. In the hospital environment, the surgeon can pass through the recovery room and see the patient, and then go back to work or home. In the surgery center environment, you are in the recovery room, and you and your staff are responsible for the patient. This will require one staff member to be dedicated to that patient until they are stable for recovery. Sometimes, that may mean staying with the patient at the facility (for a fee) or accompanying the patient home in a private duty nursing role. With cosmetic procedures, the general patient population is older and many of the patients are medically compromised. This adds an entirely

different spin on the anesthesia delivery. In addition, these cases can last 5 to 6 hours. Extracting four wisdom teeth from a healthy 16 year old with intravenous sedation is much more simple than performing a 4-hour osteotomy or face-lift on an older patient with medical problems.

In this author's experience, the biggest problem is obtaining repeatable anesthesia support. Anesthesiologists and nurse anesthetists are nationally in short supply, due in part to the recent popularity of remote surgery centers. Our experience has been that a nurse anesthetist will charge \$100 (US) per hour, and physician anesthesiologists charge at least twice that amount. It has been difficult to find anesthesia support 2 to 3 days per week and this remains our biggest challenge. This author and his staff will perform intravenous sedation with ketamine, Versed, and propofol on healthy, American Society of Anesthesiologists (ASA) Class I and II patients with straightforward procedures, but relegate to professional anesthesia assistance for compromised patients or extremely long cases. Our office maintains the same standards as the local hospitals in terms of preoperative laboratories. Determined by their age, patients must present with preoperative physician history and physical, electrocardiogram, coagulogram study results and possibly other tests. This is also a time-consuming process to coordinate the laboratory work and make sure it is back to the oromaxillofacial surgeon in time for surgery. This will take up a lot of time, for which ever staff member is in charge.

When dealing with surgery center patients, no insurance is accepted and no payment plans are generally used. Patients are required to pay the full fee for surgery and anesthesia up front. If you do not like paperwork, then you will not like accreditation. I would say that our routine daily paperwork doubled after accreditation. Whereas we had a single form for surgery, anesthesia, recovery, and follow-up, we now have dedicated forms for all of these, and more. Despite this increased paperwork, it truly does make a more comprehensive and safer patient record. In the event of a lawsuit, our records are much more complete and comprehensive than they were prior to accreditation. Furthermore, the surgeon must dictate operative reports for all cases done at the surgery center. This may seem distasteful to many, but it is truly the right thing to do and makes for superior medical record-keeping.

As stated above, we did have to purchase some specialized equipment, but it was minimal. The back-up power supply was required. We purchased an anesthesia machine because we wanted to be able to perform comprehensive procedures (Figure 4-5). We also purchased an OR surgical table because we knew we would be performing longer procedures (Figure 4-6). The



FIGURE 4-5 A refurbished anesthesia machine purchased by the author, to have the ability to perform orthognathic and cosmetic surgery procedures in the office surgery center.



FIGURE 4-6 A used operating room table purchased for the surgical center. Great savings are appreciated when using durable and reliably refurbished equipment, and prolonged surgical procedures are best performed on a fully adjustable table.

anesthesia machine, OR table, and just about any other hospital-grade equipment are available for significant savings in used condition from many sources.

In conclusion to this portion of this chapter, initial accreditation was a task of awesome proportions. It was hard work for many of the team, but relatively little work for the doctor. There is no doubt that it has made me a better surgeon and made my office a better and safer place to have surgery and anesthesia. I would wholeheartedly recommend it to any oromaxillofacial surgeon who wants his/her practice to be all that it can be and better than the rest.

Radiowave Surgery in Oral and Maxillofacial Surgery

Joe Niamtu III

Four-megahertz radiowave surgery is a new technology with many applications for our specialty, including dentoalveolar, orthognathics, and cosmetic facial surgery. In essence, radiowave surgery can be used for virtually any application for which a scalpel is traditionally used. In fact, when one considers the cost savings of not having to buy scalpel blades and the safety features of not getting stuck or cut, a practitioner could probably purchase a radiowave system for what was traditionally spent on blades.

Prehistoric humans used sharpened objects to incise soft tissue, and for centuries, open fires and red-hot instruments were used to cauterize and sear bleeding tissue. Albeit refined, the same technology persisted until the discovery of electricity. Radiowave surgery has been shown to be an improved modality in soft tissue surgery.¹⁻⁷ The use of electricity for surgical incision and coagulation dates back to its discovery. Before raw alternating current could be used for surgery, a generator was required that could produce the high-frequency current. This was developed in 1889 by Thompson, who noted heat in his wrists when immersed in saline solution while passing a current through his hands.⁸ In 1891, d'Arsonval showed that electric currents with frequencies of greater than 10,000 Hz failed to cause neuromuscular stimulation and the associated tetanus response.^{9,10} Oudin modified d'Arsonval's equipment in the 1890s to generate a spray of sparks that caused superficial tissue destruction.¹¹ Work continued at refining the use of electrical current, and in the late 1890s and early 1900s, the use of electrodes was conceived to concentrate the density of the current. The use of electrodes enabled control of the spark and was successfully used to treat lesions and reported in 1900.¹² In 1907, de Keating-Hart and Pozzi introduced the term *fulguration* (from the Latin word *fulgur*, meaning lightning). This referred to the superficial carbonization resulting when the spark from an Oudin coil was used to treat skin.¹¹ In 1909, Doyen introduced the term *electrocoagulation* (from the Latin word *coagulare*, meaning to curdle).¹³ This was used to describe the tissue response when touched

by an electrode while an indifferent electrode (antenna) was attached to the patient. The indifferent electrode allowed for the removal of the current entering the patient and channeled the electricity back into the electrosurgical unit. This prevented the buildup of static electricity so that electrical shocks were not caused to the patient or the operator. This recycling of current allowed the use of lower voltages with increased amperages and along with the biterminal electrode arrangement allowed for deeper tissue coagulation compared with previous surface carbonization.¹¹ This circuitry set the stage for the device configurations used today.

In 1923, Wyeth used electrosurgery for actually cutting tissues instead of merely charring or desiccating them. He developed an apparatus called the endotherm knife,¹⁴ which not only cut, it also sealed off smaller blood and lymphatic vessels.

William Bovie, a Harvard physicist, developed a practical electrosurgical device in 1928 that offered both cutting and coagulation modes,¹⁵ which led to the modern machines used in today's hospital operating rooms.

Radiowave surgery is not "electrosurgery." Dr. Alan Ellman, a practicing dentist, patented the 4.0 MHz wavelength radiowave surgical system in 1999. There are significant differences between electrosurgery and radiowave surgery in both the mechanisms and the tissue response.

Radiowave Surgery Principles

The optimum radiosurgery wave is a frequency of 4.0 MHz, which is similar to the frequency of marine band radios.^{16,17} Figure 4B-1 shows the range of frequencies used in different applications.

Radiofrequency machines operate by using a 60-cycle AC electrical (ordinary household) current, which is converted to a DC current by a rectifier. The DC current then passes through a coil or rectifier, which actually generates the radio waves. These radiofrequency waves pass through a high-frequency waveform adaptor, which can

modify the shape and magnitude of the radio waves, thus producing the desired waveforms used in surgery. The Ellman Surgitron IEC II (Ellman International, Inc., Helwett, NY) is representative of the latest dual-frequency radiowave technology and is discussed in this article (Figure 4B-2).

The radio waves are transferred from the electrode tip to the patient and are returned to the machine by a neutral antenna plate. The neutral electrode plate does not need to contact bare skin. Impedance to the passage of the radio waves through the tissue generates heat within the cells, which boils intracellular tissue water, creating steam, and the resulting vaporization results in either cutting or coagulation of tissue.¹⁸ The steam generated from the energy transfer causes the cell inner pressure to increase from the inside out (explosion). This phenomenon is referred to as cellular volatilization.¹⁹ This frequency does not cause the actual electrode to heat but precisely delivers the energy. Frequencies below 3 MHz will heat or melt the electrode. Proprietary surgical tungsten electrodes (Ellman Empire Micro Needle, Ellman International, Inc.) are produced, which resist damage and retain their fine tip. These electrodes are matched to the 4 MHz for precise cutting.

Four-megahertz radiofrequency surgery should not be confused with conventional electrosurgery, electrocautery, or diathermy surgery. With radiofrequency surgery, no electrical contact needs to be made between the patient and the Teflon-coated neutral antenna (see Figure 4B-2). Unlike the electrocautery (or diathermy machines, as they are referred to in the United Kingdom), the radiofrequency electrode does not provide resistance and remains cold. The tissue provides the resistance. A cautery machine, however, uses lower frequencies and the passage of current through the electrode filament, which provides the resistance and is heated. In the purest sense, this is similar to a soldering iron or wood-burning tip. This arrangement provides significant lateral tissue damage. Since radiofrequency generates less heat than conventional cautery, less

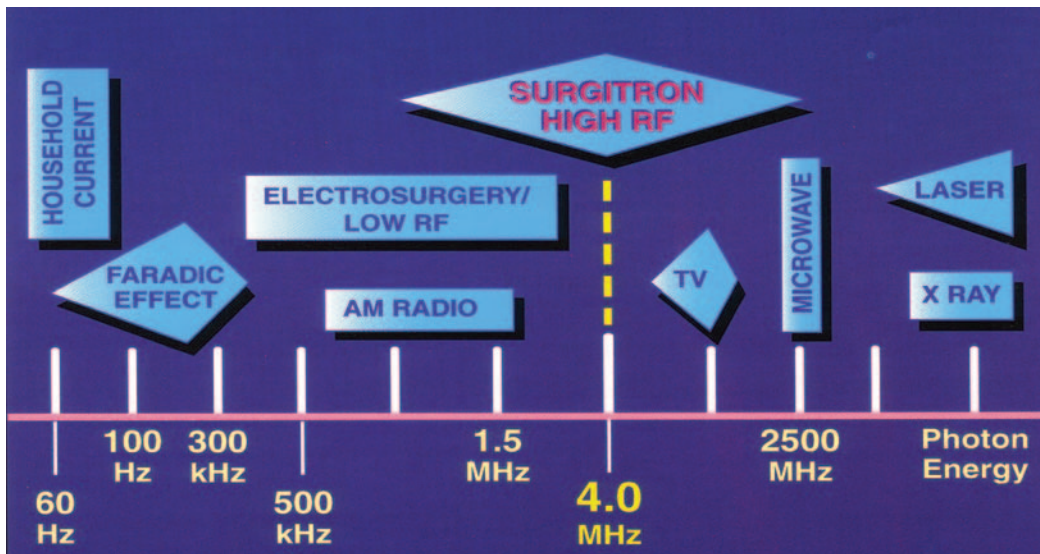


FIGURE 4B-1 The 4.0 MHz wavelength of radiofrequency is comparable to that of a marine band radio.

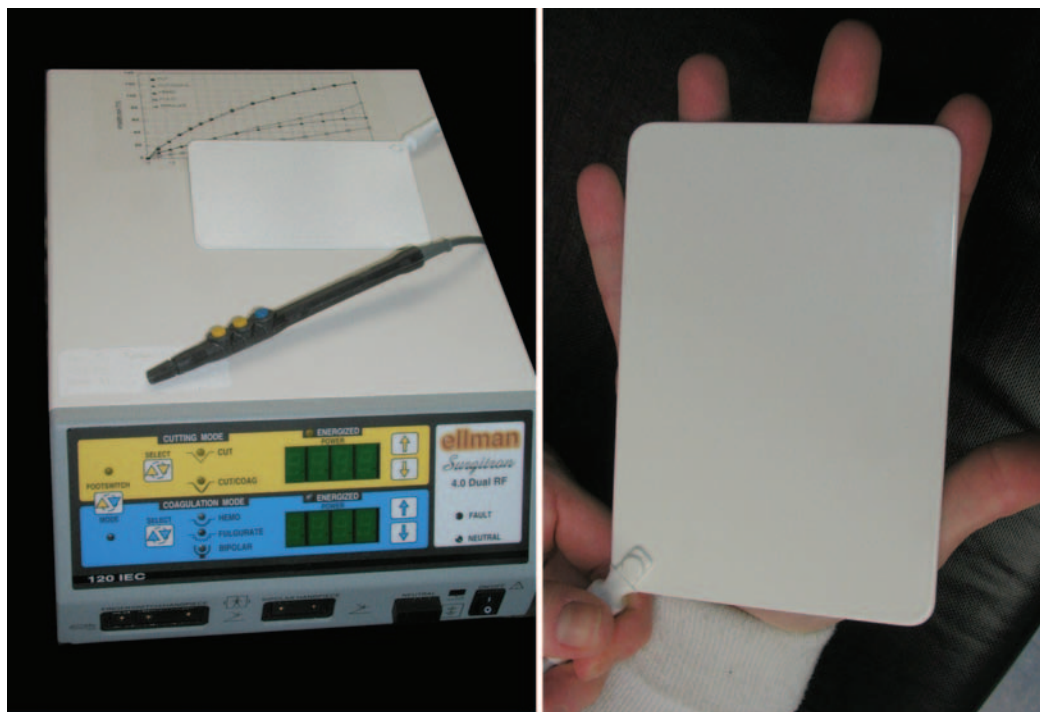


FIGURE 4B-2 The Ellman dual-frequency Surgitron IEC II has notable advantages over conventional electrosurgery and is well suited for cosmetic surgery applications.

collateral damage is seen and therefore faster healing. Bridenstine found biopsies done with radiofrequency incision to have thermal damage zones of 75 microns, which is comparable to the CO₂ laser.¹ Other studies have confirmed minimal tissue damage and comparable biopsy margins with scalpel excision.^{20–22}

The high-frequency radiowaves are modified by filtering and rectification to produce four distinct waveforms:

1. *Cutting*. This waveform consists of 90% cutting and 10% coagulation. This is a fully filtered waveform for microsmooth cutting with little tissue damage and concomitant coagulation. Histologically, this is the fastest healing waveform.
2. *Cutting/coagulation*. This waveform consists of 50% cutting and 50% coagulation. It is designed for equal amounts of cutting and coagulation and is especially useful in

vascular areas while maintaining minimal amounts of lateral heat and tissue damage.

3. *Hemostasis*. This waveform consists of 10% cutting and 90% coagulation and is designed for direct and indirect hemostasis techniques. Its use does not create charring or necrosis. This waveform can also be used to perform unipolar and bipolar coagulation.
4. *Fulguration (spark gap)*. This waveform is designed to generate a shower of sparks, which provides maximum char and necrosis. High lateral heat and maximum hemostasis are produced with the fulgurating waveform, which is used for intentional destruction of diseased tissue.

To use the optimum characteristics of radiowave surgery, adjacent tissue damage must be limited. Time of tissue contact, power intensity, waveform, and frequency of application are the variables that contribute to the lateral thermal tissue destruction, as illustrated in the formula below:

$$LH = \frac{T \times I \times W \times S}{F}$$

where LH is lateral that, T is time, I is power intensity, W is waveform, S is surface area, and F is frequency.

The amount of time that the electrode contacts the tissue is obviously paramount to prevent excessive lateral tissue damage. The faster the electrode passage, the less tissue damage is produced. A rate of 7 mm/s was proposed by Kalwarf and colleagues.²⁰ A metaphor to this principle would be using a clothes iron. If you move the iron over a shirt and keep moving, you will have even heat distribution, but if you leave the iron in one spot for too long, you will have a scorch in that area owing to excess heat.

The power intensity is also critical for proper technique. Optimum intensity will allow a smooth and effortless passage of the active electrode through the tissue. Too low of a power setting will cause sticking of the tissue and offer resistance or dragging. An excessive power setting will carbonize the tissue and cause sparking.

The frequency setting also affects the amount of lateral heat generation, as well as the healing results. A lower frequency (traditional electrosurgery) generates a less efficient cut and produces more heat, additional postoperative discomfort, and increased healing time. The optimum frequency for minimum tissue destruction is 4.0 MHz.

The waveform contributes to lateral heat and treatment destruction as well. The fully filtered current produces the least heat, whereas the fulguration waveform generates the greatest amount of heat.

Finally, electrode size is another significant variable in the formula of heat generation. A large

electrode tip requires more power and therefore produces more lateral heat when compared with a thinner electrode.

Passive Electrode

The passive electrode is also called an antenna, a passive antenna, a neutral antenna plate, or an indifferent electrode. This plate acts like a radio antenna by attracting the radio waves emitted from the machine and channels the energy back into the unit. The passive electrode is coated with a Teflon material to eliminate the possibility of burns or shocks (see Figure 4B-2). Since the passive electrode is not technically a grounding electrode, it does not need to contact bare skin and may be placed over clothing. Some practitioners merely place the passive electrode under the cushion of the surgical table under the patient’s shoulder. The closer the passive electrode to the surgical site, the less power is required; thus, there is less chance of lateral thermal damage. Placing the antenna close to the surgical site will provide better reception of the surgical antenna, just as extending the antenna on a cellular telephone increases the reception signal. The passive electrode plate is usually not placed under the head as there is less surface area, so placing it under the shoulder is adequate. The passive electrode is not necessary when using the bipolar mode.

Active Electrode

The active electrode is the energized tip of the radiowave system. The microtip is used to direct the radio waves through the tissue to make the incision. The radio waves cause the incision, not the electrode tip. This is one of the main differences between radiowave surgery and “electrosurgery.” The active electrode tip can be bent to better navigate anatomic surfaces and angles. Many different types and configurations of electrode tips are available. Straight electrode tips are the most frequently used for tissue incision. Tungsten microneedles, such as the Empire Micro Needle, have become very popular for ultrafine incisions, such as blepharoplasty and lesion removal (Figure 4B-3). These tips are very fine and long-lasting.

Loop electrodes (Figure 4B-4) are also popular for the excision of pedunculated lesions, and diamond-shaped electrodes are available that enable an elliptical incision for better closure. The Ellman Vari-Tip electrode consists of a fine wire that passes through a sleeve. The wire can be extended or retracted to adjust for the depth of the cut. In addition, the small diameter of the Vari-Tip requires reduced power settings and produces little collateral tissue heating. I prefer this tip for rhytidectomy of a fine skin incision. Although the pointed microelectrodes are well suited for fine incision, they are conical in cross

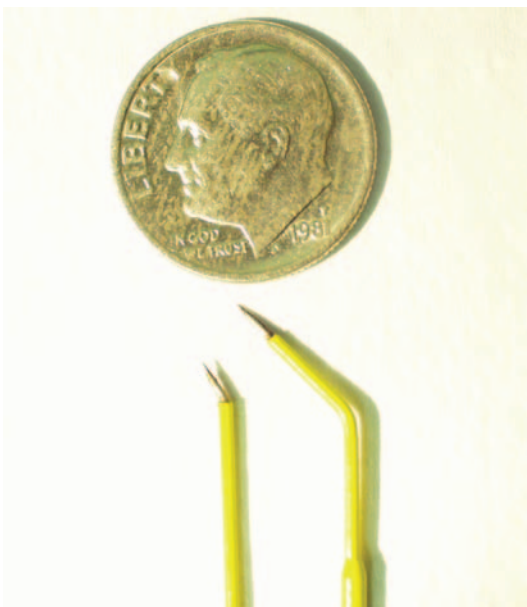


FIGURE 4B-3 The Ellman Empire tungsten electrode.



FIGURE 4B-4 Loop electrodes can be bent to accommodate a hard to reach place.

section, and the deeper they pass through the skin, the wider the incision, whereas a fine wire has the same diameter throughout its length.

Ball and flat cylindrical electrodes are used for coagulation of bleeding tissue and vessels as well as ablation of soft tissue lesions, such as nevi and keratoses. Other specialized electrodes are available for endoscopic brow-lift procedures, palatopharyngoplasty, tympanoplasty, palatal graft harvesting, tonsil and turbinate shrinkage, depilation, and ablation of telangiectasias.

Advantages of Radiowave Surgery

Multiple advantages exist with radiowave surgery when compared with scalpel incision, electrocautery, and laser soft tissue incision and coagulation (Table 4B-1).

The most significant advantages of radiosurgery are simultaneous cutting and coagulation without significant lateral tissue damage. This reduced heat promotes less postsurgical pain and faster healing.¹⁻⁷ Another advantage is a pressureless incision. Since the radiowave

Table 4B-1 Advantages of Radiowave Surgery
Incision without applying pressure (pressureless incision)
Simultaneous hemostasis
Bacteria-free incision
Artifact reduction in biopsy compared with electrocautery
The ability to bend or shape the cutting electrode for anatomic variation or working in cavities
Produces scarring equal to or better than scalpel or laser incisions
Pays for itself in not having to purchase scalpel blades
No accidental scalpel injuries
No dealing with dull scalpel blades
Minimal safety precautions when compared with lasers

electrode channels the current to the tissue and does not cut by heat, it is merely glided through the tissue. Owing to the increased control and tactile sensitivity, the incision is more precise. This is especially evident when cutting very thin or mobile tissues, such as eyelid skin, oral mucosa, or earlobes. Typically, scalpel incision in these areas requires pressure and causes dragging or bunching of the tissue.

Biopsy artifact damage is also reduced with radiowave surgery. Turner and colleagues showed that when compared with CO₂ and neodymium:yttrium-aluminum-garnet lasers, there is significantly less tissue damage, which can affect the diagnostic ability of the pathologist.⁷ They also reported the pure cutting waveform of radiowave surgery to approach the quality of cold knife excision.

A bacteria-free incision is also possible with the radiowave electrode. Although the electrode does not heat, the resistance of the soft tissue causes a release of energy and produces steam within the cells, which causes vaporization and sterilization. In addition, the electrode may be “steam cleaned” by holding the electrode between the layers of moistened gauze and activating the unit. This causes the electrode to spark and produce steam, which is self-cleansing. This also allows the electrode to be easily cleaned of debris. Unlike the electrocautery tip, which is cleaned with abrasives, the surgical debris may be easily removed by passing the electrode tip through wet gauze and activating the current.

Clinical Applications in Cosmetic Facial Surgery

Four-megahertz radiowave surgery is a technological advance over traditional electrosurgery. Radiowave surgical technique can be applied to virtually any incisional situation in which one would traditionally use a scalpel, scissors, and, in many cases, laser.

Radiowave Blepharoplasty

One of the most useful indications of radiowave surgery is cosmetic blepharoplasty. This modality produces scars consistent with scalpel incision but produces significantly more hemostasis. In addition, the ability to cut the thin tissues of the eyelid without pressure or tissue drag is impressive.

The CO₂ laser is an excellent tool for cosmetic blepharoplasty but is not accessible to many practitioners. In addition, the Ellman radiowave surgery unit is portable and does not require the doctor, patient, and staff safety precautions that the laser does. Welchs showed histologically that the 4.0 MHz radiowave surgery causes less thermal damage on resected periorbital fat pads when compared with the CO₂ laser.²

The surgical technique for blepharoplasty involves the usual markings and local anesthetic injections. The skin incision is performed with the Empire Micro Needle with a pure cutting waveform (90% cutting, 10% coagulation). Skin and muscle bleeders are controlled by grasping the area with small forceps and touching the radiowave tip to the instrument. After skin excision, the pure coagulation setting is used and a strip of orbicularis muscle is excised and coagulated in the same manner. The orbital septum is opened, and the fat pads are identified and gently elevated with forceps and their base cauterized with the Empire Micro Needle. No clamping is necessary as the cutting and coagulation with the radiowave electrode are excellent. I have performed over 100 radiowave blepharoplasties with excellent hemostasis.

I have performed side-by-side comparisons with 4.0 MHz radiowave surgery with the CO₂ laser for upper blepharoplasty. Figure 4B-5 shows blepharoplasty and laser incisions on the same patient. The Empire Micro Needle was used with a pure cutting or a cutting/coagulation (partially rectified) setting on the left eyelid and the Coherent Ultrapulse Encore CO₂ laser was used with an 8-watt continuous-wave setting on the right

eyelid (Figures 4B-6 and 4B-7). As shown in the images, both modalities provided a virtually bloodless surgical field. In addition, the radiowave surgery side showed a more esthetic scar in the early postoperative period. At the 3-month comparison, the blepharoplasty scars were judged equal by trained observers and the patients.

For lower blepharoplasty, I prefer the transconjunctival approach. The conjunctiva and capsulopalpebral fascia are incised with the Empire Micro Needle and the fat pads are identified and sectioned as previously mentioned using the Empire needle (Figure 4B-8), a small ball electrode, or the Ellman #133 electrode (Ellman Intl., Oceanside, NY).

Radiowave Rhytidectomy

I have used the microneedle or Vari-Tip electrode for pre- and postauricular rhytidectomy incisions on a pure cutting mode and have seen the same healing results as those with scalpel incision (Figure 4B-9). In addition, the subcutaneous dissection may be performed with the Empire Micro Needle and hemostasis of the superficial muscular aponeurotic system (SMAS) and muscle is easily performed with the large ball electrode or Ellman bipolar forceps or simple conduction through Addison forceps (Figure 4B-10). Having the ability to cut and coagulate without having to pick up a bipolar or similar instrument makes

surgery more simple and the field less cluttered. I also use the large ball electrode to shrink irregular contours from plication or lumpy areas of the SMAS. This not only recontours these irregularities, it also causes shrinkage and retraction of the SMAS (Figure 4B-11). Finally, greater control and dexterity are available when performing cutbacks and excess skin removal during the face-lift.

Lesion Removal

One of the true strengths of 4.0 MHz radiowave surgery is lesion removal. All practitioners have seen patients present with hypopigmented depressed scars on their face from liquid nitrogen ablation of lesions (Figure 4B-12). This all too frequent scenario can be prevented by using 4.0 MHz radiowave surgery to ablate lesions. The #133 electrode is a flat cylinder that can be used at low power with minimal lateral tissue damage. A small ball electrode can also be used for this. In the case of suspicious lesions, the loop electrode may be used at pure cutting power to perform a shave biopsy. This low power does not cause enough artifact to impede histologic analysis. For most lesions, such as nevi and verrucae, the area is anesthetized with local anesthesia and the unit is set to the cutting/coagulation setting. I use surgical loupes and wipe away successive layers of tissue while wiping the char between passes. The



FIGURE 4B-5 A 12-month postoperative scar when the right lid was incised with the CO₂ laser and the left lid with the Ellman Radiowave Micro Needle.

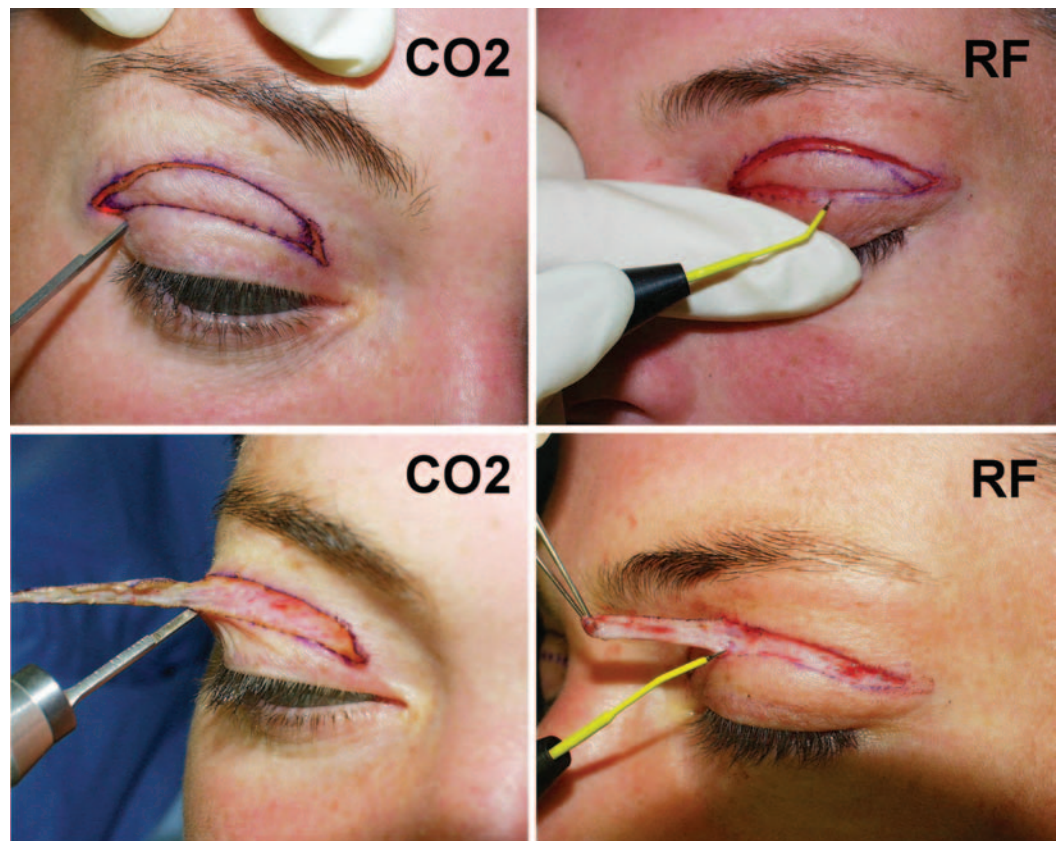


FIGURE 4B-6 The images on the *left* show the CO₂ laser and the bloodless skin incision and excision. The images on the *right* show the same bloodless surgery using an Ellman Empire Micro Needle with a pure cutting mode.

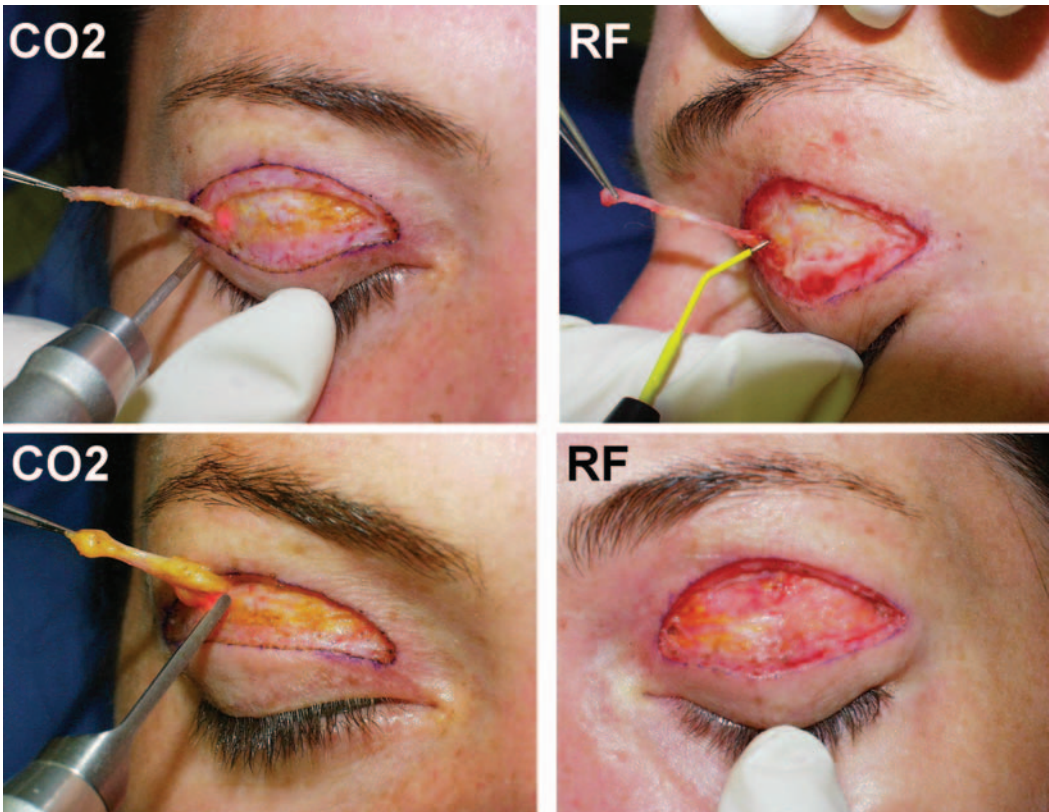


FIGURE 4B-7 The equally bloodless surgical field when removing muscle and fat from the upper eyelids.

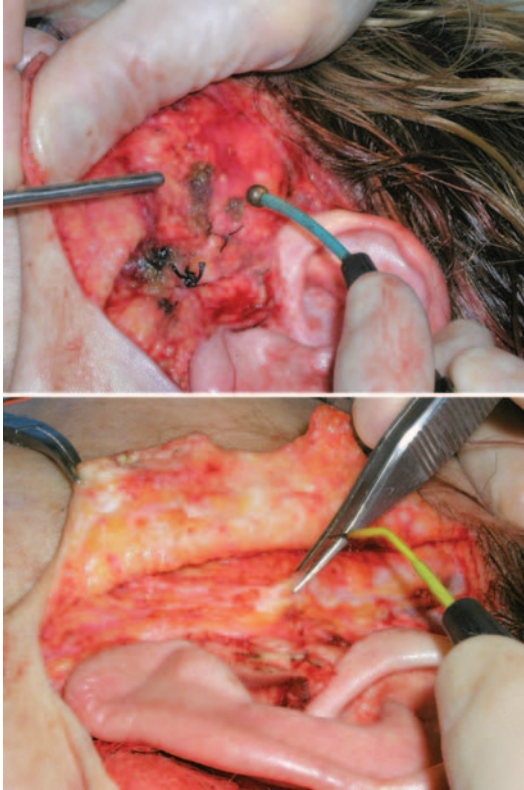


FIGURE 4B-10 Coagulation can be performed with the ball electrode or instrument conduction.

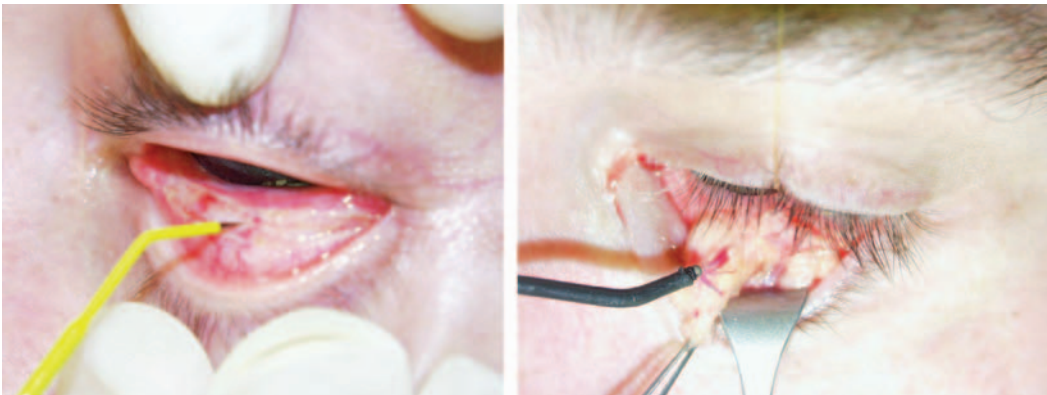


FIGURE 4B-8 The conjunctiva and lower lid retractors are incised with a cutting/coagulation current, and the fat pads are contoured with a small ball electrode.

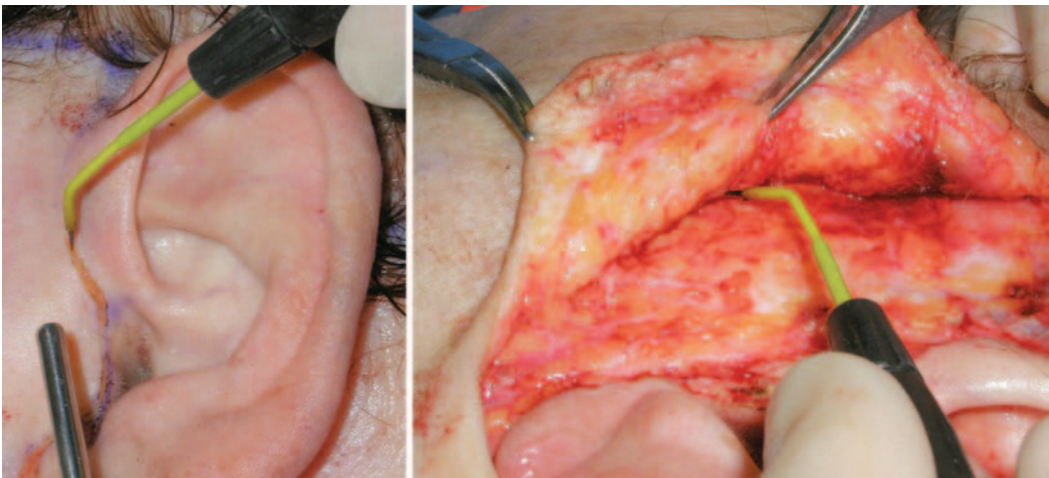


FIGURE 4B-9 The Ellman Empire Micro Needle is used to make the skin incision and to dissect the superficial muscular aponeurotic system from the skin flap.

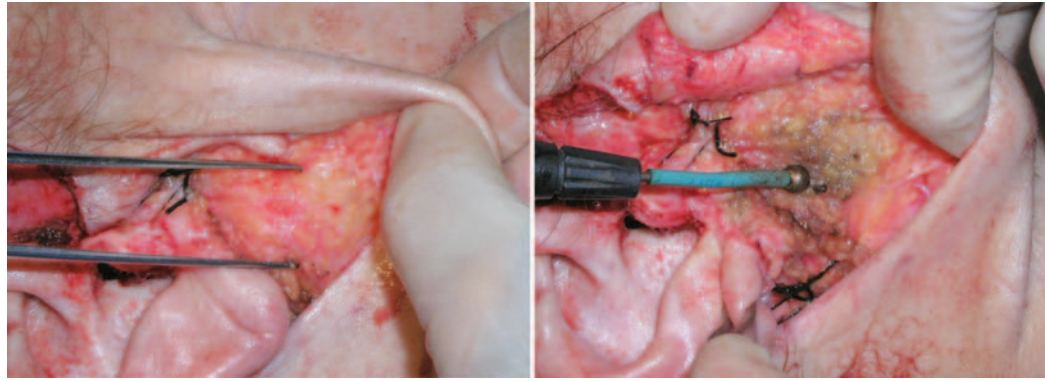


FIGURE 4B-11 A preauricular protuberance of the superficial muscular aponeurotic system after placing placation sutures. This mound may be shrunk and flattened by gentle cauterization with the ball electrode.



FIGURE 4B-12 Unsightly, depressed, hypopigmented scars frequently result from aggressive lesion ablation techniques, such as liquid nitrogen.



FIGURE 4B-13 Multiple nevi and skin tags removed with radiowave surgery.

lesion is treated just to its base or slightly beyond. It is better to remain conservative and tell the patient that he or she may require a touch-up to remove a remnant lesion than to overtreat and end up with a depression. When treated in this manner, facial lesions leave imperceptible scars, as shown in Figures 4B-13 and 4B-14.

Mobile Tissue Incision

Incising fleshy or mobile tissue is always a challenge. One problem with scalpel incision of fleshy or mobile tissue is that pressure is required, which distorts the tissue and decreases control and precision. The fine-tipped radiowave electrodes, when used at the proper settings, simply glide through the tissue without pressure. This pressureless incision technique is excellent for eyelid tissue, earlobes, and oral mucosa (Figure 4B-15).



FIGURE 4B-14 Low-power ablation with the Ellman radiowave system and #133 electrode produces minimal lateral tissue damage, thus producing little scarring.

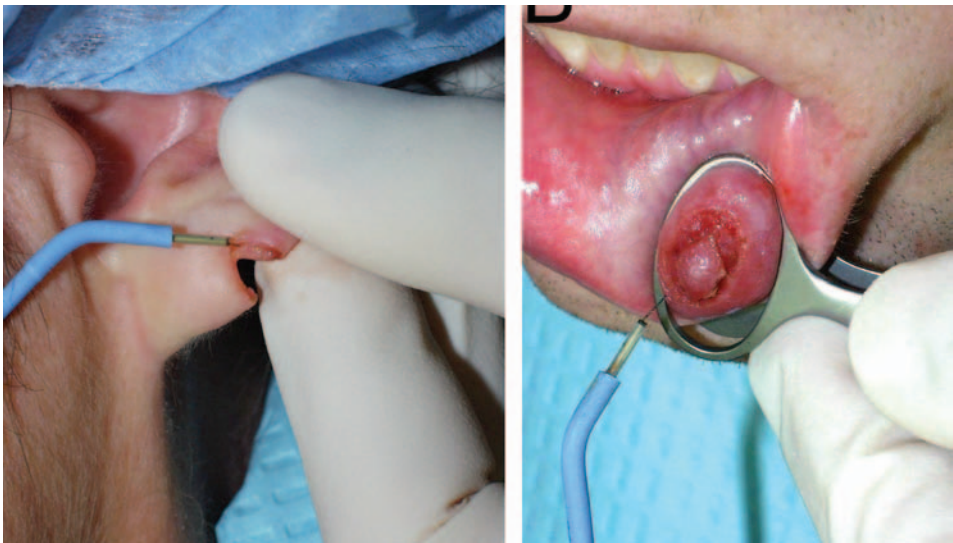


FIGURE 4B-15 The figure illustrates the ability to make a pressureless incision on mobile tissues for earlobe repair and a lip lesion.

Specialty Applications

A wide variety of specialized electrodes are available for cosmetic applications. The Ellman Mucotome is an electrode that is specifically designed for harvesting palatal mucosa (Figure 4B-16). These mucosa grafts are used for lower eyelid reconstruction and various maxillo-facial applications. The Mucotome not only cuts an exact thickness of mucosa, it also simultaneously coagulates the very vascular palatal tissues. Long contoured electrodes are made for endoscopic brow and forehead lifting, as shown in Figure 4B-17.



FIGURE 4B-16 Mucotomes are specially designed to harvest palatal grafts of various widths.

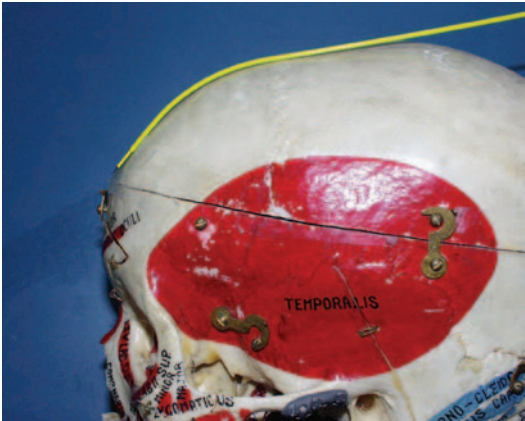


FIGURE 4B-17 Many specialty electrodes are available, such as this curved, elongated electrode for endoscopic surgical applications. A curved electrode used for endoscopic brow surgery is shown.

Again, any procedure that can be performed with a scalpel or electrosurgery can be performed with 4.0 MHz radiowave surgery. I use the Empire Micro Needle for osteotomy incisions (Figure 4B-18). This produces less heat and promotes faster healing.

Hazards, Complications, and Caveats

Like any modality, radiowave surgery presents certain hazards and complications (Jon Garito, Ellmann International, Inc., personal communication 2003).^{23,24} Excess lateral tissue damage is probably the most common complication and usually results from operator error (especially novice clinicians) by failing to observe the lateral heat formula discussed previously. Choosing optimal power settings and the correct electrode and ensuring continuous movement, with care not to pass too slowly through the tissue, will

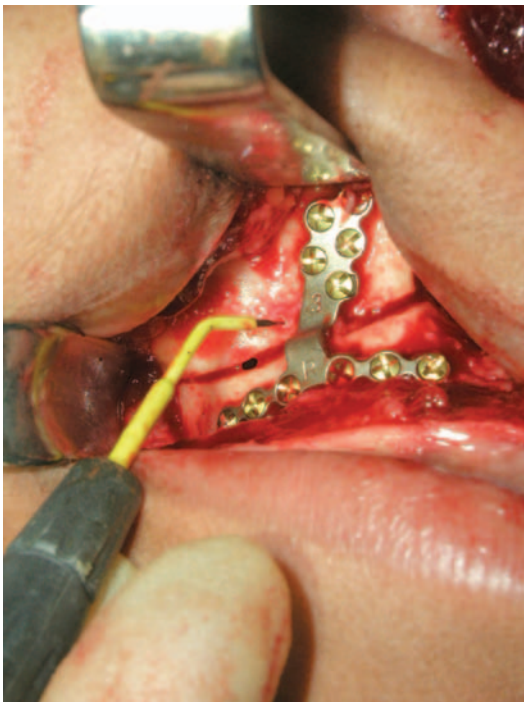


FIGURE 4B-18 The Ellman 4.0 MHz radiowave system is well suited for orthognathic and reconstructive procedures.

prevent increased tissue damage. Understanding the lateral heat formula is critical to an optimum clinical response. Radiowave surgery should not be used in the presence of flammable anesthetics, liquids, or skin preparations. Just as the laser plume can be detrimental, radiowave surgery causes tissue vaporization and potential smoke hazard from particulate inhalation. Precautions include careful and controlled smoke plume evacuation and wearing surgical masks rated for microparticle filtration. Although not a complication, inadequate removal of smoke will cause an unpleasant smell throughout the office. If central suction is used, it must be vented to the outside environment otherwise; you are merely redistributing the smoke and smell from one area of the office to another. Special portable evacuation systems are available with viral and activated charcoal filters for both operator and patient safety and comfort. Radiowave surgery machines may also interfere with other electromedical equipment, such as monitors. In my office, interference with the electrocardiography monitor was corrected by plugging the radiowave machine into a separate circuit from the monitor. Pacemaker interference has been a major concern in the past but is only a problem with older, nonshielded pacemakers. Most modern pacemakers are shielded from external radiation and therefore are not a problem. Several surgeons exist that themselves have implanted pacemakers

and routinely operate with radiowave surgical units without a problem.²³

The potential exists for interference with implantable cardioverter-defibrillators (ICDs). LeVasseur and colleagues reviewed this topic and made recommendations, including possible deactivation of the ICD prior to surgery.²⁴ The electromagnetic interference of radiowave surgery may cause the pacemaker to reprogram or otherwise malfunction. In the case of ICDs, the interference may cause the device to fire a cardioversion sequence or reprogram the device. In the case of an ICD discharge, the surgeon is in no danger of electrical shock because the discharge is not transmitted, but it may induce dysrhythmias in the patient.

When radiowave equipment is used in the presence of cardiac pacemakers or defibrillators, a cardiology consultation should be obtained. It is possible that the cardiologist may elect to temporarily inactivate the device during the surgical procedure. Intraoperative cardiac monitoring and emergency cardiac medications should be on hand in the rare case of a cardiac emergency.

Bipolar use of radiowave surgery is safer when operating on pacemakers and ICDs as current is concentrated across the tips rather than through the patient. Short bursts of radiowave surgical energy (less than 5 seconds) are preferable to long electrode activation periods. Pauses between the bursts allow resumption of cardiac rhythm.²⁴

Conclusion

Four-megahertz radiowave surgery is a new technology that provides many benefits in cosmetic surgery. Decreased heat and lateral tissue damage, controlled hemostasis, faster healing, adaptability of specialized electrodes, increased tactility, increased operator and patient safety, and cost-effectiveness are notable advantages. All of these advantages are applicable to the very vascular and sometimes mobile tissues in cosmetic facial surgery.

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4C

Rejuvenation of the Lip and Perioral Areas

Joe Niamtu III

It would have been a lot easier to write this chapter 10 years ago, as there were significantly fewer options available for lip and perioral enhancement in the mainstream armamentarium of the cosmetic surgeon. Collagen and fat injections, cutaneous dermabrasion for wrinkles, and some selected surgical lifting procedures generally summed up the available options. The introduction of CO₂ laser resurfacing in the early 1990s and the US Food and Drug Administration (FDA) approval of Restylane (Medicis Inc, Flagstaff, AZ) were landmarks in treatment options. Much has happened in a short time, and the remainder of this chapter will deal with this exponentially expanding arena.¹⁻¹¹

Over the millennia, women have been accentuating their lips for purposes of beauty, courtship, and sexuality (Figure 4C-1). Some

societies still go to great lengths to draw attention to the lips (Figure 4C-2). It can be said that the lips are the only exposed sexual organ in our contemporary society, although in some societies this facial region is covered for modesty per local religious customs. Historically, full lips have come in and out of fashion. Pictures of movie stars from the 1940s and 1950s reveal that the use of dark lipstick with large lips was fashionable in that period. Moving ahead a decade or so into the 1960s, lips were seen to be often deemphasized with clear or gloss lipstick. Big voluptuous lips are currently back again and will continue to come in and out of fashion. I personally believe that the other reason that lip enhancement has become so popular is the fact that the baby boomers have entered their fifth decade and are driving cosmetic surgery. More women are in the

workplace and have discretionary income to spend as they please. In addition, minor cosmetic enhancements are no longer a stigma. In the 1960s, a Clairol hair color advertisement stated, “Only her hair dresser knows for sure,” as if coloring one’s hair was a secret of the universe! Today, many women have multicolored hair and brag about it! In celebrity circles, it has become fashionable to brag about cosmetic procedures, and the entire experience has come out of the closet. With the advent of Botox (botulinum toxin A; Allergan Inc, Irvine, CA) injection and other “lunchtime” procedures, minimally invasive cosmetic enhancements have become a cottage industry for many specialties. Who is better trained to deal with the lips than oral and maxillofacial surgeons? Few specialties have as much experience in treating the lips and perioral areas,



FIGURE 4C-1 Humans have adorned their lips for as long as there has been recorded history.

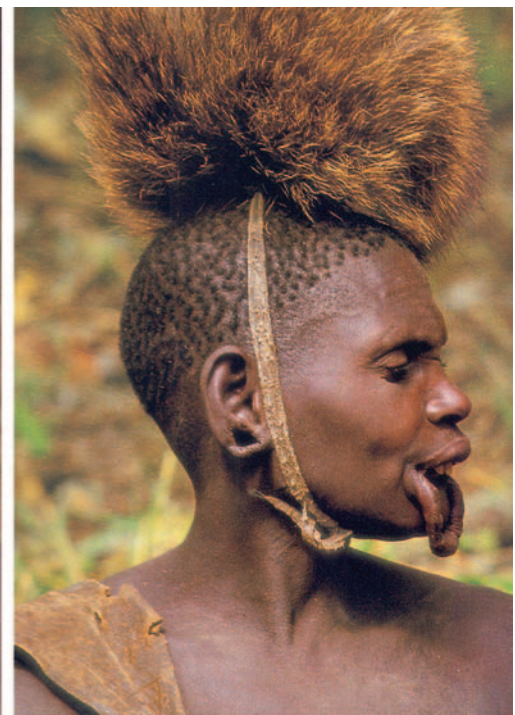
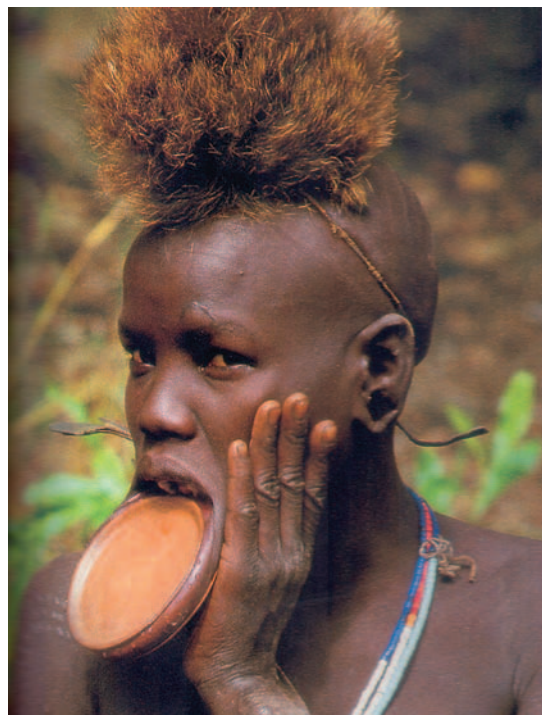


FIGURE 4C-2 The lips play an important part in beauty, courtship, and mating. Some cultures go to extreme measures to accent the lips.

and cosmetic rejuvenative options can be a mainstream part of our practices.

Lip Anatomy

An esthetic lip means different things to different people, as beauty is in the eye of the beholder. Statistically and artistically, the upper lip consists of one-third of the total lip volume, and the lower lip, being larger, consists of two-thirds of the lip mass (Figure 4C-3).

The esthetic upper lip has a “lazy M” configuration at the vermilion–cutaneous junction, commonly referred to as “Cupid’s bow” (Figure 4C-4). This junction has a “white roll,” which is a defining outline and the result of light reflection from this area. The lower lip is more curvilinear and also frequently has a similar white roll. The other defining feature of the upper lip is the philtral complex, which consists of the philtrum and the philtral columns. This area is frequently overlooked when performing esthetic lip augmentation.

In youth, the perioral skin is smooth, and nasolabial folds are minimal until the third decade. Females frequently develop “lipstick lines” that manifest as vertical rhytids radiating

outwards from the vermilion–cutaneous junction. These lines are frequently accentuated in smokers and are not usually seen in males, presumably from the presence of hair follicles in the area. Females disdain these lines, not only from the cosmetic aspect of looking old, but also because lipstick tends to run outwards from the lines, producing an undesirable appearance.

As people age, the lips undergo atrophy for multiple reasons. The effects of gravity and actinic damage coupled with the decreased vertical dimension resulting from enamel tooth wear often produce changes in the lips that make them seem to disappear (Figure 4C-5). The skin at the commissures begins to sag, and the formation of mandibulolabial folds causes depressions at the corners of the mouth, which are often referred to as marionette lines. The descent of the malar fat pads coupled with the loss of perioral volume and deepening of the nasolabial folds shape the aging midface.

Treatment Options for the Lips and Perioral Areas

Today’s facial surgeons have more options than ever before to rejuvenate the perioral area. For decades, bovine collagen was the standard of care for facial and lip fillers. It is a product that was generally well suited for augmentation but presented significant drawbacks. First and foremost is the fact that it is an animal-derived substance and can cause allergy reactions, thus preinjection testing is a necessity. Second, it does not last long, frequently being resorbed within 4 to 6 weeks. Alternate fillers with obvious advantages have been used in other countries for decades but were slow to gain FDA approval. In December 2002, the hyaluronic acid-based filler Restylane gained FDA approval and began the revolution in new fillers. Restylane is hyaluronic acid and is derived from bacterial fermentation. Since it is a natural

resident of many body tissues, allergic reaction is quite rare and is usually related to protein loads from the bacterial processing. The other huge advantage is the fact that studies have shown Restylane to last as long as 8 months.¹¹ This longevity is related to a process termed isovolumic degradation (Figure 4C-6).

As the hyaluronic acid molecules become phagocytized, water is drawn into the molecule from the surrounding tissue, thus replacing the lost molecular volume. For this reason, the hyalurons last longer in vivo and have become the filler of choice for most practitioners.

Sculptra (poly-L-lactic acid; Dermik Aesthetics, Bridgewater, NJ) has received FDA approval for the treatment of lipoatrophy in human immunodeficiency virus (HIV) patients. Antiretroviral medications have greatly improved the survival of HIV patients but cause atrophy of facial fat, especially in the midface and temporal regions. Sculptra comes packaged as a solid that must be diluted with saline 24 hours before injection (Figure 4C-7).

Unlike most other fillers, Sculptra does not provide immediate augmentation. When the poly-L-lactic acid particles are injected, an inflammatory response is initiated and results in the formation of new collagen in the area. This process usually takes 3 to 4 weeks and the effects can last

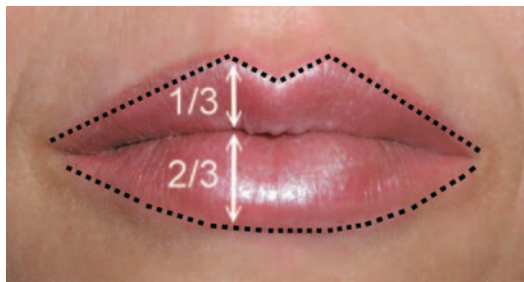


FIGURE 4C-3 The upper lip is smaller than the lower lip and represents one-third of the total lip volume.

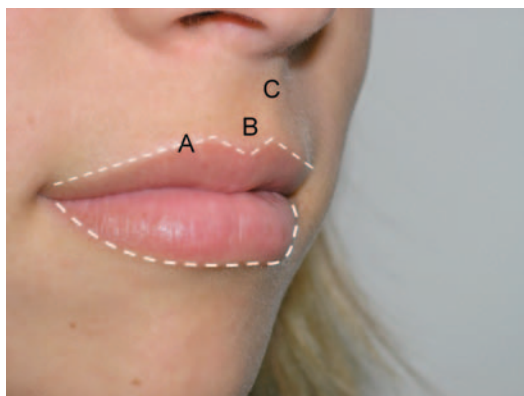


FIGURE 4C-4 Defining features of esthetic lips. The “lazy M” of the upper lip and the curvilinear outline of the lower lip are shown by the broken lines. A = white roll; B = philtrum; C = philtral column.



FIGURE 4C-5 The senescent changes of the lips and perioral area are manifested by loss of lip volume and skin changes from aging and sun damage.

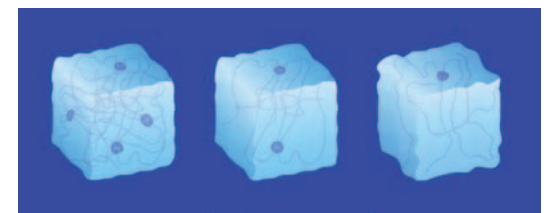


FIGURE 4C-6 Process of isovolumic degradation. Water molecules are drawn into the hyaluronic acid complex as the product is naturally degraded; thus the molecule retains its shape and fullness over the degradation process.



FIGURE 4C-7 Sculptra consists of poly-L-lactic acid and requires premixing prior to injection.

40 Diagnosis and Treatment Planning

1 to 2 years. As of the time of writing this chapter, Sculptra is only FDA approved for the treatment of HIV-associated lipoatrophy.

Most maxillofacial surgeons are well experienced in the use of hydroxyapatite (HA) for hard tissue grafting. Radiesse (Bioform Biomedical, San Mateo, CA) contains HA particles of 25 to 125 microns in an aqueous gel and is FDA approved as a radiographic marker and a filler for vocal cord abnormalities. It is used off-label to augment facial wrinkles, folds, and lips. Because of the calcific nature of HA, the product can last for 12 to 18 months. In my opinion, it is a filler that is best used by experienced injectors as it is very technique sensitive. Improper injection techniques can result in lumpy areas. Again, the fact that some fillers last a long time can be an advantage, but in terms of complications, this can be a distinct disadvantage. Figure 4C-8A shows Radiesse being injected, and Figure 4C-8B shows a before and after image of Radiesse augmentation of the nasolabial folds. This filler is generally injected in the immediate subdermal (superficial subcutaneous) area.

Fat has been used as an injectable filler for the past 100 years. It has fallen in and out of favor, but recent techniques popularized by Coleman had initiated renewed interest in fat use.¹⁰ The development of tumescent local anesthesia has popularized and simplified fat harvesting and injection.^{2,4,8} Fat injection has multiple advantages. It is readily available for most patients, is a natural tissue, and has the feel of native tissue when injected. Various techniques exist for fat harvest and injection. I inject tumescent local anesthesia (0.1% lidocaine and 1:1,000,000 epinephrine) in the periumbilical region and wait for 15 minutes. A 10 cc syringe with a harvesting cannula is used to harvest the needed amount of fat from a stab incision in the umbilicus. The fat is harvested in the immediate subcutaneous area. Volumes from 10 to 90 cc of fat are typically harvested at a single session. The fat can be centrifuged, although I prefer to allow gravity to separate the supernatant from the fat. The fat is emulsified by pushing it back and forth between two 10 cc syringes coupled with a female–female Luer-Lock connection until the fat becomes a creamy consistency. The fat is then injected in the face and/or lips in various tissue planes. In order to provide vascularity to nourish the harvested adipocytes and to slow resorption, the fat is injected in deep, intermediate, and superficial tissue planes. It can be injected with dedicated blunt cannulas (Coleman Fat Injection Cannulas, Byron Medical, Tucson, AZ) or simply with an 18 gauge needle. Care must be taken when injecting fat (or any filler, for that matter) in order to avoid inadvertent intravascular injection. Blindness has been documented with fat and filler injections,

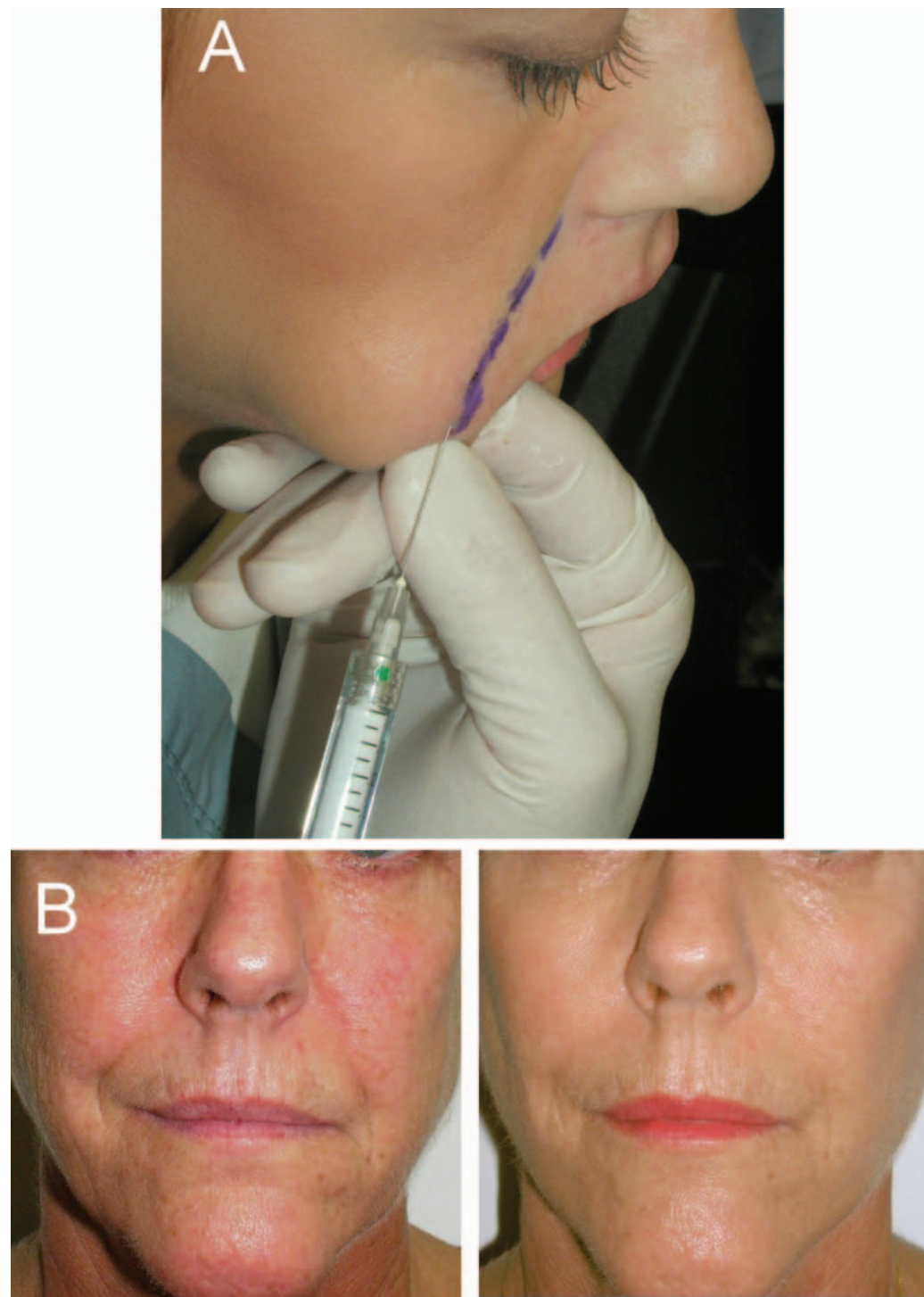


FIGURE 4C-8 A, Radiesse being injected into the subcutaneous plane in the nasolabial fold. B, Before and after image of a patient injected for nasolabial improvement with Radiesse.

especially in the upper face and periorbital areas. Although many theories exist, I feel that some adipocytes will survive and become viable, and much of the injected fat will be resorbed over time. For this reason, multiple injection sessions may be required to obtain a lasting result. Excess fat can be frozen at the time of harvest and injected later, or multiple harvesting and injection sessions can be performed. Since the fat will invariably resorb, overcorrection is usually performed

when injecting. This produces a relative cosmetic deformity and may take up to several weeks to look normal.

Figure 4C-9 shows a young male patient who had undergone radiation treatment for a malignant orbital tumor in childhood. The radiation stunted the temporomandibular joint and facial growth on the right side. The patient was treated with fat that was harvested from the abdomen and injection into the face (Figure 4C-10).



FIGURE 4C-9 A young male patient who had undergone radiation treatment for a malignant orbital tumor in childhood, stunting the temporomandibular joint and facial growth on the right side. The patient was treated with a single session of 100 cc of harvested fat from the periumbilical region.

Silicone is a filler that has also fallen in and out of favor for facial and lip augmentations. It has been used in a nonscientific manner for years by professionals and, unfortunately, also by nonprofessionals. Early techniques used such additives as olive oil, and nonmedical-grade silicone for machine lubrication was also injected. Although the FDA performed multiple studies, the studies were poorly controlled and provided little to advance silicone as a safe filler. The injection of large amounts (lakes) of silicone in the tissues and the problems encountered with breast implants largely caused silicone to fall out of favor with most injectors. When large amounts of silicone are injected, they are known to migrate to distant sites via tissue planes. This problem, coupled with foreign body giant cell reactions and even tissue necrosis, caused the FDA to outlaw the use of injectable silicone in the 1980s. Finally, several liquid injectable silicone preparations were approved by the FDA as a tamponade treatment with retinal detachment. Silikon 1000 (purified polydimethylsiloxane) is a highly purified long-chain polydimethylsiloxane trimethylsiloxy-terminated silicone oil marketed by Alcon Laboratories (Fort Worth, TX). The viscosity of liquid injectable silicone is measured in centistokes (cs). One centistoke is the viscosity of water. A liquid of 1,000 cs (Silikon 1000) has the viscosity of honey. Those practitioners who have used

injectable silicone for decades will argue that no better filler exists. Silicone is a thick gel and feels extremely soft and natural when injected. It is a permanent filler and when used correctly provides excellent results. When a filler is classified as permanent, one must keep in mind that although the actual filler material may persist, aging, ptosis, and actinic damage will continue with the aging process in any given area. Tough lessons have been learned in terms of injecting large volumes of silicone into the tissues and the process is contraindicated. The proper method for silicone injection is the microdroplet technique. Microdroplets (0.01 cc) of liquid injectable silicone are placed in the subdermal plane. Small amounts of silicone (0.1 cc per lip quadrant) are injected in these tiny microdroplets. The body will form reactive collagen around the microdroplets and wall them off, which produces the augmentation and keeps the silicone at the injection site. These small amounts of silicone are injected on a monthly basis until the desired results are obtained. In actuality, the treatment is stopped short of the desired result, as collagen will continue to form. This treatment is not an immediate phenomenon and may take 3 to 9 months to achieve a result. Silicone is injected as a facial filler for off-label use. Figure 4C-11 shows silicone injected into the nasolabial area of a patient with HIV-associated lipoatrophy. I would caution any

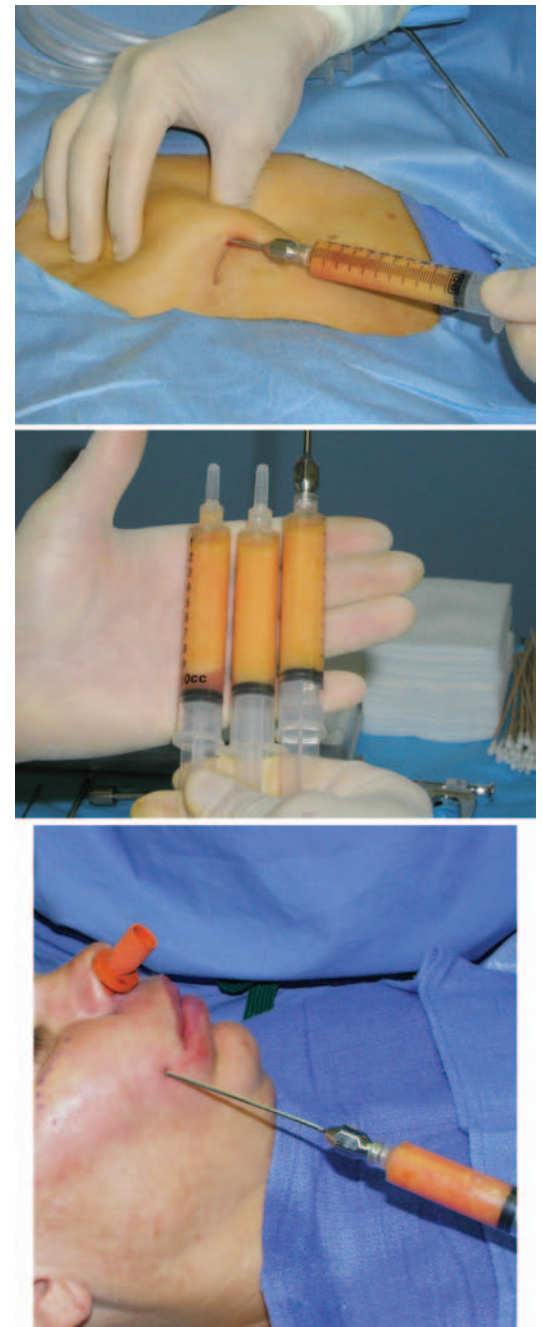


FIGURE 4C-10 The periumbilical region is a favored region for fat harvest (top photo). The harvested fat is decanted or centrifuged in syringes to separate the fat from other fluids (middle picture) and then is injected into the facial tissues in multiple tissue planes (bottom photo).

injector to carefully consider the use of silicone as a facial filler, as any complication would result in significant collegial criticism. It should be used by only the most experienced injectors, and it is never a mainline treatment for a patient who has never had fillers. Being an FDA-approved product with an off-label use, it is illegal to advertise cosmetic silicone injections, and its use must be consistent for the product. Lipoatrophy in HIV patients would be an example of an accepted indication. The liquid injectable silicone is drawn

from the vial with an 18 gauge needle and injected with a 25 to 30 gauge needle. It is important for the injector to keep his/her finger off the syringe plunger when going in and out of the skin so that the silicone is not inadvertently deposited in the epidermis, which will cause fibrous bumps. Figure 4-35A shows a silicone injection in the nasolabial folds of a patient with HIV lipoatrophy from antiretroviral drugs, and Figure 4C-11B shows the silicone vial and injection syringe.

Human Collagens

Human cadaveric collagens such as Dermalogen (Collagenesis Inc, Beverly, MA), Cymetra (LifeCell Corporation, Branchburg, NJ), Fascian (Fascia Biosystems, Beverly Hills, CA), and Alloderm (LifeCell Corporation) were introduced and used but have fallen out of favor for newer fillers.

Isolagen (Isolagen Inc, Houston, TX) is a filler made from cultured autologous fibroblasts. A punch biopsy is harvested from the posterior auricular area and sent to the company for fibroblast tissue culture. Again, this product is not significant in the filler marketplace. Although the product came from the actual patient, the need to harvest, send off, culture, resend, and inject appears to be too much of a process for the average injector and doctor.

Combination Fillers

Artecoll (Artes Inc, San Diego, CA) is a filler consisting of 30 to 42 micron polymethylmethacrylate (PMMA) beads in a bovine collagen vehicle. This product has been used in Europe since 1994 and is currently under FDA investigation to be marketed as Artefill in the United States. The allure of this filler is the fact that it is permanent. I feel that permanent fillers can have permanent

complications, and these fillers should be used very judiciously and only by very experienced injectors.

Dermalive and Dermadeep (Euromedical Systems, Ltd., Nottingham, UK) are fillers that have been used in Europe since 1998. These products are semi-permanent biphasic implants that consist of a fluid carrier and a solid phase in a 60% (hyaluronic acid) and 40% (nonresorbable acrylic hydrogel) volume, respectively. After injection, the hyaluronic acid resorbs first, and then the hydrogel particles become encased in new collagen and endure for up to 12 months. This product is currently not FDA approved.

The extensive and ever-expanding armamentarium of facial fillers will continue to present treatment options for doctors and patients. What is more important than the actual filler used are the techniques of injection and the results. Some fillers work better in the hands of some doctors, and one should adhere to what works for one's patients.

Techniques of Filler Injection

Anesthesia

Pain control is important in any practice, but especially in an elective cosmetic practice where patients do not really have life-threatening reasons to be there in the first place. The injection of fillers is performed in different ways by different doctors. Almost everyone uses topical anesthesia, but the use of local anesthesia is variable. Personally, I use local anesthetic blocks or infiltrations for all lip enhancements but not usually for skin injection.¹²⁻¹⁹ On presentation, the patient is put in a consult room and topical anesthesia is applied. I prefer a combination of 20% benzocaine, 6% lidocaine, and 4% tetracaine and purchase this product from Bayview Pharmacy, Baltimore, MD.

If the patient is scheduled for nasolabial fold or skin wrinkle augmentation, no additional anesthesia is used unless the patient is too uncomfortable. For lip injection, I use infraorbital and mental nerve blocks or, more commonly, local anesthetic infiltration in the upper or lower anterior vestibule from cupid to cupid region. This usually provides adequate local anesthesia for treating the lips.

Treatment Decisions

Experienced patients may know exactly what they want in terms of lip enhancement, but many patients "leave it up to the doctor" as to what to do. It is extremely important to deliver what the patient desires if it is in fact rational or possible. Some patients have unrealistic expectations, and when altering the lips with long-lasting fillers it is imperative to "do the right thing." It is helpful to take before and after pictures to show patients average treatments. Patients who have esthetic lips to begin with are the best candidates for novice injectors as it is easy to make them look better. Patients with thin, ill-defined, or senescent lips are difficult for even the most experienced injector.

The absolute key to learning about fillers is to be conservative. I tell my patients that injecting fillers is a sculpting process and not a single treatment. All patients are rescheduled for a 2-week follow-up. At this follow-up, it is decided if any touch up is needed or if any asymmetries exist and if the patient is satisfied. Furthermore, it must be decided in advance (usually in the informed consent) on who will pay for any touch-up or re-injection.

In general, when performing a consultation for fillers, the doctor should determine what exactly the patient wants and select the appropriate filler. The patient should be instructed about the positive and negative effects of the filler, and the recovery and longevity should also be discussed. Overselling a result or longevity can cause problems, so it is always preferable to be realistic. Generally, I discuss with patients their desires, which are usually outline and plumping for the lips and decreasing fold and lines on the skin. Almost every single patient will express a desire to avoid overdone lips.

If the patient has a well-defined Cupid's bow, then I will usually not address this and confine the injection into the deeper portion of the lip to increase volume. Many patients only need plumping in the middle one-third of the lip and will look unnatural with fullness extending to the commissures. This is variable and must be discussed with the patient. If the patient has a poorly defined white roll or Cupid's bow, then this area is augmented with the intention to duplicate a white roll using filler to outline the "lazy M" configuration discussed above. Some patients may want

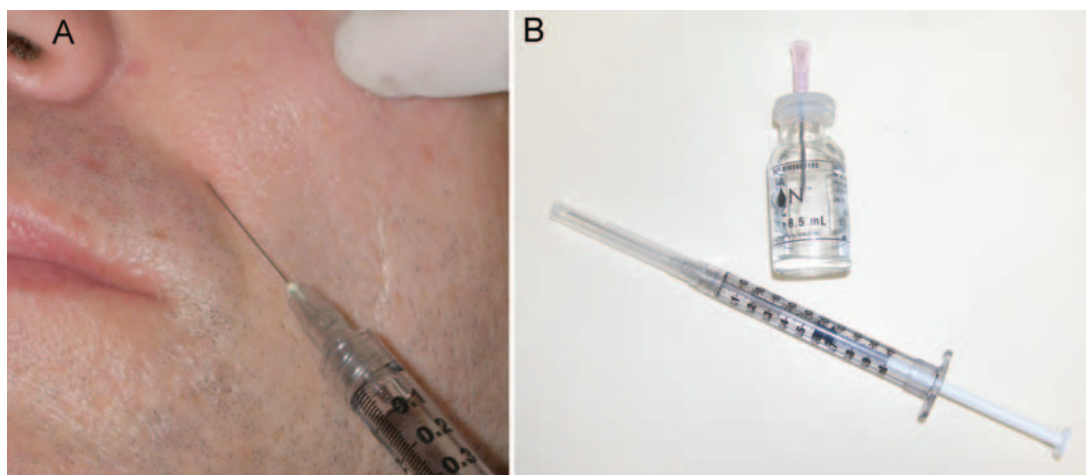


FIGURE 4C-11 A, Silicone injection in the nasolabial folds of a patient with human immunodeficiency virus lipoatrophy from antiretroviral drugs. B, The silicone vial and injection syringe.

or need augmentation of both the lip outline and the deeper volume. Although most patients desire better looking lips, many older patients will present with the desire to efface lipstick lines. This can be a difficult thing to do with fillers only. By injecting multiple vertical lines, one can build a series of “speed bumps” if not careful. Although one can inject these lines individually, I prefer to address them by either recreating the white roll or plumping the entire lip, which will stretch the lines. I also explain to these patients that alternate procedures such as laser resurfacing may be necessary to achieve their desired result.

When addressing nasolabial folds, I explain that fillers will not eliminate the folds, but rather will blunt them. I further explain that adults would look unnatural if they had no nasolabial folds. One problem that exists with lips, folds, and wrinkles is when the patient will not purchase the adequate amount of filler to do the job. Fillers are obviously expensive, but underfilling an area will usually disappoint a patient. In my experience, a single syringe may suffice to augment an upper lip and possibly a portion of the lower lip. If both lips need attention, then two syringes are probably necessary. Similarly, it is a rare situation where a single syringe of filler will augment two nasolabial folds. This must be explained to patients or they may be unhappy or feel that the treatment did not work.

Oral commissures are an area that can also take a lot of filler and produce minimal results. When patients request filler injection to “turn up the corners of the mouth,” they should be made aware that it may take multiple syringes and that the results will be mild to moderate. Other facial wrinkles may respond very well to dermal injection. The glabella, cheeks, and lateral canthal region are popular areas for filler injection. It is also favorable to use Botox in some areas such as the upper face when contemplating fillers. By reducing the movement of underlying muscles, the fillers will frequently last longer.

Injection Techniques

Several common injection techniques exist. Linear threading is a method of injecting a continual line of filler while keeping the syringe moving forward or backwards. This is the same mechanism used when putting a line of toothpaste on a tooth brush. Serial puncture is another technique and involves injecting separate beads or boluses of fillers in a similar means as decorating a cake with medallions from a frosting injector. This technique puts down small beads of filler. In reality, most injectors use a combination of both these techniques. Linear threading is good for generalized injecting and serial puncture techniques are good for filling in gaps or fine-tuning small areas. When using serial puncture techniques, it is important to keep the

filler beads close together so as not to have a bumpy appearance. Figure 4C-12 shows a diagram of linear threading and serial puncture.

Lips

After the patient discusses their desires, I usually end up injecting either the white roll area or the deep portion (parenchyma) of the lip or both. Some patients may also get separate injections in the vertical lip rhytids or at the oral commissures. Still others may on occasion get injected in the mentolabial region and marionette lines. Eighty percent of my lip injections involve deeper injection and 20% involve outline techniques.

White Roll Outline

The goal here is to accentuate the white roll and Cupid’s bow area to provide definition, especially in the “lazy M” region. As mentioned above, photographs are taken, topical and local anesthetics are performed, and the lips are wiped with alcohol.

The most difficult step for the novice injector is where to put the filler. Zyplast, Zyderm, Cosmoplast, and Cosmoderm (Allergan, Santa Barbara, CA) are superficial-dermal fillers. Restylane and Captique (Genzyme Corp. Cambridge, MA) are mid-dermal fillers. Restylane Fine Line and Perlane (Q Medical AB, Uppsala, Sweden), not yet available in the United States (at the time of this writing), are a superficial-dermal filler and a deep-dermal filler, respectively. Silicone, fat, Radiesse, and Sculptra are subcutaneous fillers. Figure 4C-13 shows the placement of a mid-dermal filler.

Since the lip does not have an organized epidermis–dermis complex, the filler is actually being injected into the potential space just under the mucosa. This pertains more to the “outlining of the lazy M,” while augmenting the white roll (Figure 4C-14). In this space, the filler should flow freely with little syringe resistance, and there is generally antegrade fill and sometimes retrograde fill as well. When in the correct space, the filler will flow and not “well up” as a lump. If the filler is too superficial, there will be considerable pressure on the syringe plunger, the tissue will “well up” as a lump of filler, and there will be no

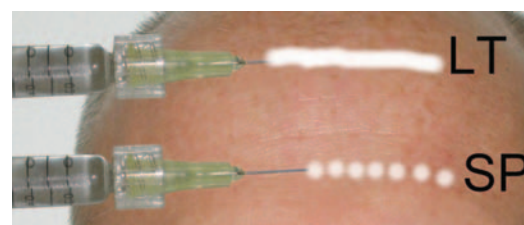


FIGURE 4C-12 Linear threading (LT) and serial puncture (SP) are common injection techniques.

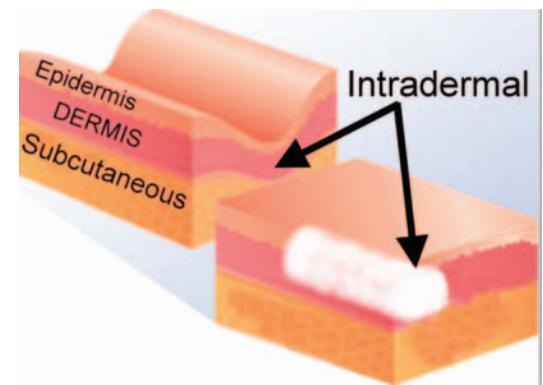


FIGURE 4C-13 Most common fillers are placed in the mid dermis. When injecting in the proper plane, there is not extreme skin blanching (indicating too superficial placement) or the inability to see the area fill (indicating too deep placement).

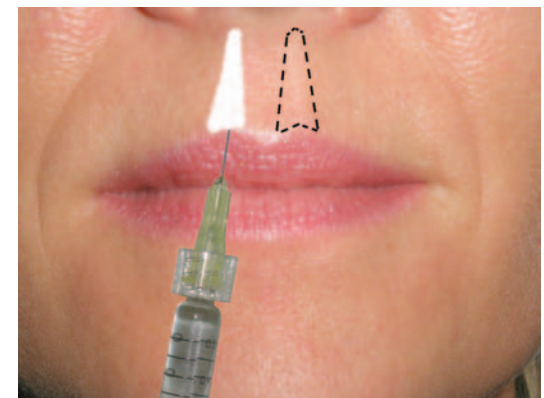


FIGURE 4C-14 The “lazy M” configuration of the upper lip and the curvilinear configuration of the lower lip are augmented with a fine bead of filler to reconstruct the white roll at the vermilion–cutaneous junction.

forward flow. On the other hand, if the filler is placed too deeply, it spreads out and does not provide the desired “roll” effect (Figure 4C-15). In other words, if you are attempting to make a roll outline, you want to be in the potential space just under the lip mucosa at the vermilion–cutaneous junction. Severe blanching may be a sign of a too superficial injection and can disrupt the vascularity, causing tissue loss.

Deep Injection

If the surgeon is trying to add volume to the lips, then a deeper injection is warranted to provide pout and to generally make the lip larger from within. This can be done in addition to white roll augmentation or as an isolated procedure. To increase the general lip volume, the needle is inserted deeper into the lip, in about the outer one-third to one-half of the lip thickness. With this technique, I usually inject at the wet–dry line and use the linear threading technique, where I am injecting on the way out (Figure 4C-16).

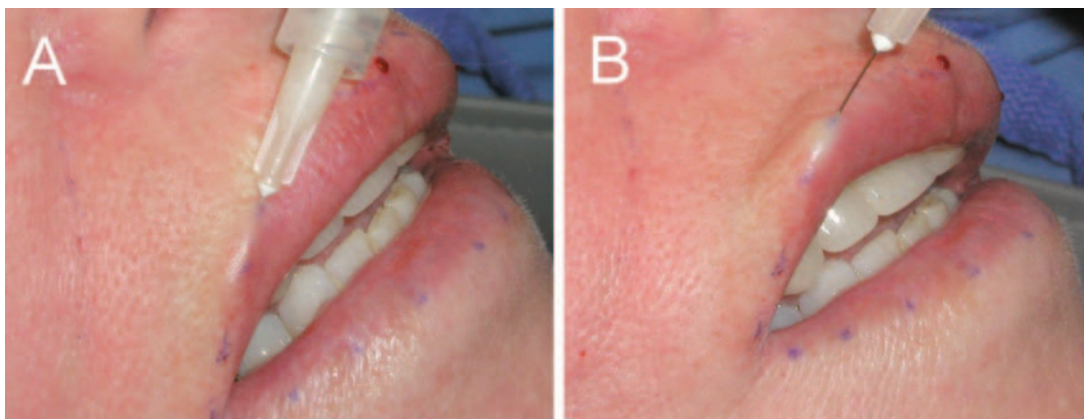


FIGURE 4C-15 A, The proper injection plane at the vermilion–cutaneous junction for white roll augmentation. The filler should flow antegrade and retrograde freely with little syringe pressure. B, An improper plane, where the filler is welling up in a bolus and blanching the tissue. There is greater syringe pressure felt as compared with the correct plane.



FIGURE 4C-16 Deeper lip injection is used to increase the volume and pout of the lip as well as to show increased vermilion mucosa. The needle is inserted at the wet–dry line.

Frequently, I will confine most of the injection to the central one-third of the upper and lower lips and taper the filler as I extend to the commissure. Some patients look better with the middle one-third augmented (what I call the kissing part of the lip), whereas others can use augmentation out to the commissures. Again, it is better to err on the conservative side as you can always add more.

Philtral Column Augmentation

Esthetic lips usually have a well-developed philtral complex. The philtrum is distinct and the paired philtral columns are well defined. I feel that this is one of the most undertreated areas when performing lip augmentation. Basically, the filler is injected intradermally to accentuate the existing columns or make new ones (Figure 4C-17). The philtral column is frequently triangular with the apex under the nostril and the base at the central portion of Cupid's bow at the vermilion–cutaneous junction. I pinch this area

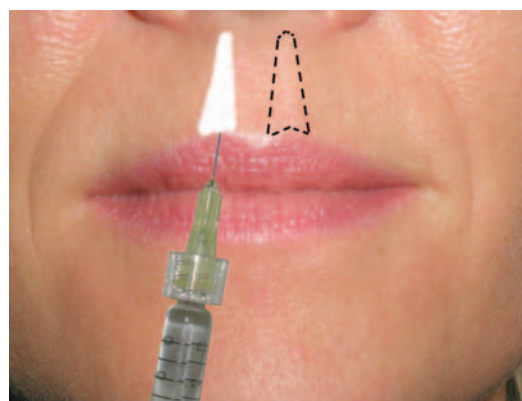


FIGURE 4C-17 The philtral columns are an often overlooked feature in augmenting the lips. Small amounts of filler in this area make a nice difference in total lip esthetics.

while injecting to corral the filler in the desired area and maintain the triangular shape.

Figures 4C-18 through 4C-22 show before and after pictures of filler injections.

Besides the lips, other perioral wrinkles can be simultaneously injected. As stated above, the vertical lipstick lines can be injected separately, but care must be used not to create “speed bumps” along the lip.

The marionette lines (mandibulolabial folds) are frequently injected by intradermal linear threading. Filling depressed commissures can also be accomplished, but in my opinion, it requires a large volume of filler and frequently does not meet the patient's expectations. Sometimes, face-lift surgery is required to pull the jowls and related tissues in a posterior–superior vector, which can make a difference in perioral facial folds. The mentolabial fold is sometimes augmented to improve lower facial esthetics.

Figure 4C-23 shows a patient before and after injection of the mentolabial folds to improve the

perioral esthetics in a patient with short lower one-third facial height.

Nasolabial Folds

The nasolabial folds represent the second most requested filler treatment in my practice and in those of most of my colleagues. As the deepening of the nasolabial folds begins by the third decade, it is often the first sign of aging that a patient sees and wants fixed. As most people age, the nasolabial folds deepen and are frequently a driving force in a patient's decision to have face-lift, laser, or other surgical procedures. One main problem that must be discussed with potential patients for nasolabial fold treatment is the fact that the folds will not “go away.” Failure to fully explain the anticipated result will lead to a disappointed patient and doctor. I explain to all patients that nasolabial folds are a natural part of facial aging, and an adult without any nasolabial folds would look abnormal, as would an infant with a mustache. I further explain that our goal in treating nasolabial folds is to blunt them, not eliminate them. I tell the patient nasolabial folds are a valley and we want to make them less deep. The next most critical factor is letting the patient know that it will probably take multiple syringes of filler to make a difference. Fillers are expensive, and many patients only desire a single syringe to split between both nasolabial folds. For all but the most minor folds, this is an insufficient amount. In my experience, most patients will require at least 2 syringes to make a difference and it may take up to 4 syringes for deep folds.

Although I rarely inject the lips without local anesthesia, I rarely use local anesthesia for nasolabial folds or other skin injections. I generally apply topical anesthesia for 10 minutes prior to injection. If this is not sufficient, then infraorbital blocks or mucosal local anesthetic infiltration is performed intraorally on the mucosal side of the nasolabial folds.

A significant and common mistake, especially with the novice injector, is to inject in the very center of the nasolabial fold. Since various tissue planes merge in this area, injecting filler material in the center of the fold can cause the filler to migrate laterally. If this happens, one can actually make the nasolabial fold bigger. In order to control the flow and location of the filler in the nasolabial fold, the filler should be injected slightly medial to the actual fold. The filler can also be massaged into the center of the fold. This is one area where I commonly use linear threading and then fill in the gaps with serial puncture. Again, when using hyaluronic acid fillers, significant swelling usually ensues immediately, so it is important not to overcorrect the folds as it becomes difficult to tell what is filler and what is swelling. I have all filler patients return in 2 weeks for follow-up and possibly touch-up.



FIGURE 4C-18 Before and after images of the lips after Restylane augmentation.



FIGURE 4C-19 The same patient shown in Figure 2-18, shown in the oblique view.



FIGURE 4C-20 This patient is shown before, immediately after, and 3 weeks after Restylane augmentation of the upper and lower lips.



FIGURE 4C-21 Before and after images of philtral augmentation with Restylane.

Taking preinjection digital pictures is also important when injecting fillers anywhere. Patients forget what they looked like and pictures are necessary to truly evaluate a result. Figure 4C-24 shows a rendering of nasolabial fold injection.

Adjunctive Procedures

Advanta Lip Implants

A discussion of lip fillers is not complete without the discussion of lip implants. Over the past decade, I have placed many Gore-Tex implants in the face.^{8,9} Although many lip implant cases are still doing well, my experience with Gore-Tex lip implants was not favorable, especially when using small strands to augment the white roll. This implant material frequently became hard and torturous. After the urging of several respected colleagues, I embarked on a study with Advanta lip implants (Atrium Medical Inc, Hudson, NH). This implant, like Gore-Tex, is made from expanded polytetrafluoroethylene (ePTFE), but the manufacturing process is quite different. The Advanta implants are designed with a dual porosity structure, as shown in Figure 4C-25. This unique design feature is responsible for the implants remaining pliable. I have placed several hundred Advanta lip implants, and I feel it is a worthwhile and predictable procedure. Early in the learning curve, I had placed several implants that were too short and required removal and replacement with larger implants. I have had one infection that necessitated removal. Several patients decided they did not want implants and I removed them. Other than that, the response and results have been extremely acceptable for both doctor and patients.

Lip implants, like other implants, are not for every patient. I usually request that a patient try fillers prior to placing an implant to make sure they like the look. I tell them that although the implant will not impede normal oral function, such as puckering and smiling, they will be able to feel the implant. I liken this to breast implants. I do not like to place them in smokers (although I have), and I do not place them in patients who play woodwind or similar instruments. I explain to the patient that the implant is reversible as they are easy to remove. Implant reversal involves minimal tissue encapsulation, and a simple cut down to the implant with moderate traction will remove them without damaging other tissue.

Procedure

Advanta implants come in various sizes and round or oval configurations. I usually use a 5 or 6 mm implant for major augmentation and 4 to 4.5 mm implants for minor augmentations. I prefer to use the round implants, although the oval ones are favored by some surgeons. The procedure takes only minutes and can be performed with local anesthetic infiltration.



FIGURE 4C-22 This patient had significant senescent changes and very hypoplastic lips. Restylane injection has restored youthful contours for this patient.



FIGURE 4C-23 Before and after images from Restylane injection for mentolabial fold augmentation to improve the lower one-third facial esthetics.



FIGURE 4C-24 The nasolabial folds are injected with care to stay slightly medial to the fold, so as not to deposit filler laterally, which will make the fold bigger. A combination of linear threading and serial puncture is used.

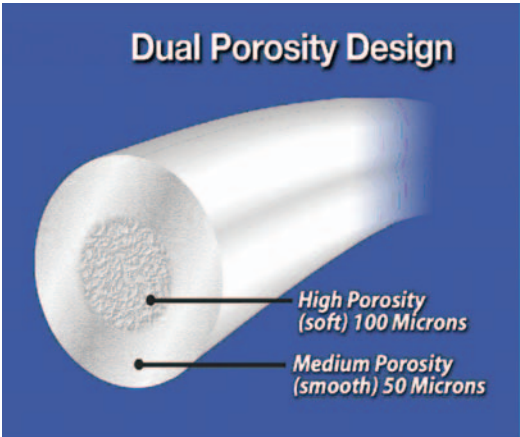


FIGURE 4C-25 The Advanta lip implant has a unique dual porosity structure that makes it different from previous expanded polytetrafluoroethylene (ePTFE) facial implants.

After sufficient local anesthesia, a stab incision is made several millimeters anterior to the commissure. If upper and lower implants will be used, then a single incision on each commissure is adequate. The pretense to placing this implant is to have the implant sit in the middle of the lip. The labial artery is located posterior in the lip at about the edge of the incisors and is rarely violated. After making the stab incision, the lip needs to be tunneled to make a space for the implant. Most of the various implant sizes can be purchased with a passing trocar that is attached to the implant. This is by far the easiest and most efficient means of tunneling and passing the implant. A passing awl or tendon passer can also be used to create the tunnel. It is imperative to stay in the same plane in the middle of the lip or the implant will not sit naturally. If a trocar is used, then the implant is simply pulled through the lip from one incision to the other. A tendon passer can be used to make the tunnel and is then passed through the lip to secure the implant and to pull it back through the tunnel. It is important to make the stab incisions big enough so as not to constrict the implant when pulling it through or it will be smaller than the actual size. The implant is ductile and some constriction is inevitable, but controllable. After the implant is passed, the lip must be stretched laterally to make sure it lies passively over the implant. I grasp the middle of the lip with both hands and stretch it laterally. I repeat this several times to ensure a passive implant. The implant then needs to be trimmed. I taper the end of the implant with scissors with several millimeters protruding from the incision. Figures 4C-26 through 4C-29 show typical implant placements. The lip is stretched one more time and the implant tails should fall just inside the incision. It is important that the implants do not protrude outside the incision or they can



FIGURE 4C-26 A, A 5 mm round Advanta lip implant. B, A tendon passer that has been tunneled through the middle of the lip. C, The implant before pulling through the tunnel. D, The implant in place prior to trimming.



FIGURE 4C-27 Before and after images of Advanta implant placement in the upper and lower lips.



FIGURE 4C-28 Before and after images of Advanta implant placement in the upper and lower lips.

extrude through the suture lines. The incisions are then closed with 4-0 gut suture. Patients are placed on antibiotics and analgesics. The healing is generally a weekend procedure, but I have seen several patients develop severe swelling that takes up to 5 days to resolve. With extreme swelling, tapering steroids are used.

Skin Resurfacing

Although fillers and implants can rejuvenate the perioral area, nothing can come close to the impact that aggressive CO₂ skin resurfacing has on this area. Cosmetic surgeons can put all the filler they want in a patient's lips and it will indeed make the lips bigger and the stretch from the filler may hide some rhytids. No filler, however, can cut through decades of skin aging like CO₂ laser resurfacing can. The aging skin is frequently a sallow color and, especially in the perioral area, can take on a pebbly appearance from actinic damage. Solar lentigos and other actinic and age-induced lesions are also quite common, in addition to dreaded vertical lipstick lines.

Laser skin resurfacing works by ablating the epidermis and upper dermis to induce a wound that produces neocollagen when healing. This ablation destroys sun damage and basal layer pigmentation, and when the wound heals it has new skin, no adverse pigment, and is a "younger" color. I never laser the perioral area as a solitary cosmetic unit. I feel that one can get away with solitary periorbital laser skin resurfacing, because the periorbital areas are recessed and blend in when confined to the skin within the bony orbit. The perioral area is quite different. I have seen too many patients treated at other offices with isolated perioral resurfacing, and they end up with a very apparent distinction between the treated and nontreated areas. A laser "milk mustache" is not uncommon. Because of this, I always perform a full face laser when treating the perioral area, to minimize the color disparity and blend the areas.^{20,21}

Figure 4C-30 shows a before and after image of a patient treated with periorbital CO₂ laser resurfacing. Note the extreme improvement of this area. In order to not overtreat this area, I will sometimes perform multiple laser procedures spaced 3 months apart.

Complications

There does not exist a cosmetic procedure that is complication free. Fillers are no different. Most complications seen with fillers concern treatment problems such as the following:

- Overcorrection
- Undercorrection
- Allergic reaction
- Bruising, swelling
- Unmet patient expectations



FIGURE 4C-30 This patient was treated with aggressive CO₂ laser resurfacing using the Lumenis Encore (Lumenis Inc. Santa Clara, CA) laser. No other single modality can provide the rejuvenation commensurate with CO₂ laser resurfacing.

- Lumpiness
- Asymmetry

Many of these problems are consistent with a learning curve and become less common with experience. A well-designed informed consent can help improve communications when problems arise. Unfortunately, if a patient is not happy with the results, they often think the doctor did something wrong. It is important to address preoperatively what will transpire with asymmetry or undercorrection. Who will pay for the extra filler? In addition, I always undersell the longevity of fillers. Promising a patient that a filler will last for an extended time can cause problems if it does

not persist. I tell them that every patient metabolizes fillers at a different rate and that I cannot guarantee specific longevity. Patients are informed that a given filler will usually last for a given amount of time, but there are no promises.

Conclusion

Perioral aging eventually affects all individuals and no specialist is more trained to treat this area than oral and maxillofacial surgeons. Perioral rejuvenation is fun and a much appreciated service by patients. By starting with conservative and low-risk procedures, oral and maxillofacial surgeons can learn these techniques and add them to their ever-expanding armamentarium.

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Need for Distraction Osteogenesis

Joseph E. Van Sickels

Distraction osteogenesis is a relatively new tool that can be used to treat dentofacial discrepancies. By creating bone, it can be used to lengthen the ramus, both of the mandible and maxilla. When used within the arch, it creates a space to resolve transverse and anterior-posterior discrepancies while allowing for the correction of crowded teeth.¹⁻⁵ Like orthognathic surgery, it can be used to treat routine skeletal discrepancies⁶; however, it offers options to correct discrepancies that are difficult or impossible to achieve with standard orthognathic procedures.^{7,8} Furthermore, it appears to offer greater stability for large movements that are not stable with standard operations.⁹ Finally, there may be a lesser incidence of sensory deficits than seen with mandibular surgery to advance the mandible.¹⁰ Distraction is frequently done in an outpatient hospital environment and may be more cost efficient than the more prolonged procedures done on an inpatient basis. It can obviate the need for bone grafts in large surgical movements of the maxilla and mandible. Its greatest disadvantage is that it requires close postoperative management and cooperation of patients and their families. Additionally, the ultimate occlusal result is not as predictable as that with orthognathic procedures. This necessitates very aggressive postdistraction orthodontic management. Specific skeletal discrepancies that can be treated with distraction can be divided into segmental deformities and whole-arch deformities.

Segmental Deformities

Mandible

Distraction within the corpus of the mandible allows correction of transverse and anterior-posterior issues. Intraarch distraction may be done with tooth- or bone-borne appliances.^{1-5,11} Although the arch may be divided anywhere, the symphysis is one of the safer and more popular regions of the mandible to do distraction in. Symphyseal distraction allows correction of transverse deficiency of the mandible, allowing an alternative to extraction of teeth to resolve crowding. Those who advocate bone-borne appliances suggest that with tooth-borne appliances, there is more tipping and less bodily movement

than seen with a bone-borne appliance.¹¹ Advocates of the tooth-borne appliance point to the relatively inexpensive cost associated with the device.¹² In adolescent patients, the maxilla can be expanded by nonsurgical means, whereas in adults, both the maxilla and mandible are expanded with surgical techniques.^{4,5} The patient in Figure 5-1 is a 12-year-old female, who presented with transverse discrepancies of her maxilla and mandible and severe crowding. She underwent 8 mm expansion of her lower arch, whereas she had a slightly greater amount of expansion of her upper arch (Figure 5-2). The author's experience is that the maxilla should be overexpanded by 10 to 15% for both nonsurgical processes and surgical-assisted rapid palatal expansion. In contrast, the mandible does not need to be overexpanded. Del Santo and colleagues found similar results for the lower arch.¹³ In their study, skeletal expansion in the mandible was greatest in the intercanine region, but secondary to postsurgical orthodontic movement, where the greatest increases in dental width were between the first molars and second premolars.

Dressner and colleagues have recently discussed the simultaneous correction of patients with anterior-posterior discrepancies and dental crowding.^{1,2} Segmentalization of the mandible is tailored to the region where the crowding is the most severe and there is space to make a corticotomy. Combinations of tooth and hybrid tooth and bone-borne appliances are used and appear to be indicated when the patient has a deep bite.



FIGURE 5-2 Four months after 8 mm of symphyseal distraction; note the space created.

Maxilla

Like the mandible, both transverse and anterior-posterior segment issues can be addressed with distraction. Transverse discrepancies of the maxilla have been addressed for years with surgical-assisted rapid palatal expansion.¹⁴⁻¹⁶ The procedure can be done under general anesthesia or intravenous sedation. It can be used to correct a unilateral or a bilateral skeletal constriction. Although somewhat controversial, most authors recommend that the pterygoid plates be fractured in order to allow for posterior expansion.^{15,16} Others suggest that the plates do not need to be fractured, especially when having the procedure done as an outpatient.¹⁴

Whereas the majority of maxillary segmental distractions have been used to address transverse



FIGURE 5-1 A, Maxilla of a 12-year-old patient, with crowding; the appliance is in place. B, Crowding in the lower arch; the appliance is in place.

discrepancies, intraarch distraction can be used to resolve crowding with or without anterior-posterior simultaneous correction. The patient in Figure 5-3 presented with crowding in the maxilla and a Class III cuspid and Class I molar. Segmental maxillary distraction was chosen as an alternative to extractions and advancement of the entire maxillary arch. This allowed resolution of the crowding while simultaneously correcting the anterior-posterior discrepancy. An appliance was placed in the maxilla several days prior to surgery (Figure 5-4). An anterior maxillary segmental osteotomy was done followed by a two-day latency period. The patient had 0.5 mm of expansion per day divided into a twice-a-day rhythm for a total of 6 mm of advancement of the anterior segment (Figure 5-5).



FIGURE 5-3 A, Intraoral frontal view. B, Intraoral profile.

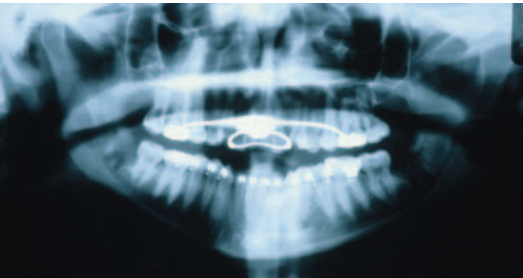
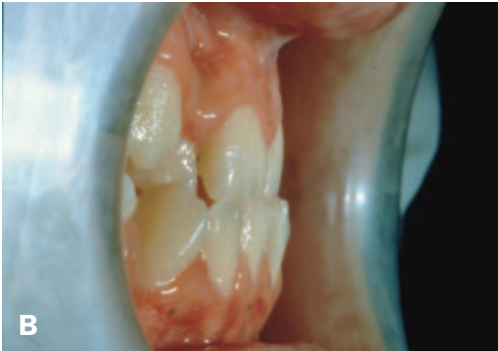


FIGURE 5-4 Panorex, with appliance in place.

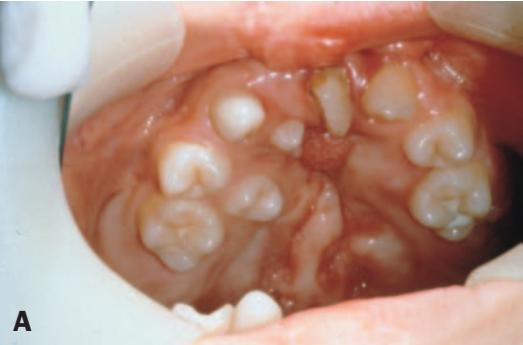


FIGURE 5-6 Maxillary occlusal view (A) and lateral cephalogram (B); note the severe anterior-posterior discrepancy.



FIGURE 5-7 Intraoperative view of vertical incisions.

aligned, her skeletal discrepancy was treated by conventional orthognathic therapy.

Whole-Arch Deformities

Mandible

Ramus
Lengthening of the mandibular ramus is highly unpredictable with orthognathic procedures, but relatively easily done with distraction.^{12,17,18} Most authors who have published results on lengthening of the ramus were treating patients with hemifacial microsomia or Treacher Collins deformities.¹⁷⁻¹⁹ Extraoral appliances have been used to achieve large advancements, but have the disadvantage of leaving pin tract scars on the face.¹² Intraoral appliances avoid this problem,

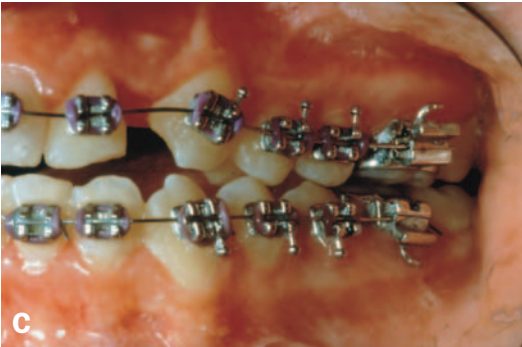


FIGURE 5-5 Frontal (A), right (B), and left lateral (C) views after distraction.



FIGURE 5-8 Maxillary occlusal (A) and profile (B) views; note the space created for the bicuspid.



but are technically more difficult to place.¹⁹ Haug and colleagues showed that intraoral appliances have a mechanical advantage over extraoral ones.²⁰

Body

Advancement of the mandible beyond 7 mm has shown increasing amounts of instability when done by a sagittal split osteotomy.²¹⁻²³ Movements beyond 12 to 15 mm are usually not possible without extraoral procedures and bone grafts. Additionally, large movements frequently require a period of maxillomandibular fixation in order to achieve stability. Distraction presents an alternative choice to advance the mandible in these cases. The patient in Figure 5-9 was followed over a 4-year period, with increasing mandibular deficiency following an unsuccessful attempt to advance her mandible and impact her maxilla. Both bone scans and serial cephalometric radiographs showed that her occlusion was stable. She had symptoms consistent with obstructive sleep apnea. Her mandible was markedly deficient with extremely small condyles. Although her condyles

were small, she did have reasonable protrusive and excursive function. She was treatment planned for a three-piece Le Fort I osteotomy and distraction of her mandible to advance it 17 mm at the inferior border. Bone-borne appliances were placed (Figure 5-10). The extrinsic vector chosen was directed toward the maxillary occlusal plane. Additional skeletal anchorage was used

in both the maxilla and mandible to allow modification of the primary vector and to resist the intrinsic pull of the suprahyoid musculature (Figure 5-11). Elastics were placed between the upper and lower skeletal fixation appliance as the mandible was advanced to create a secondary extrinsic vector. The skeletal fixation in the mandible was fabricated from four-hole bone plates and fixed with a single bicortical screw to the genial region below the apices of the teeth. The patient had a 6-day latency period followed by a 1 mm a day rate of expansion divided into a twice-a-day rhythm. She was advanced to an end-to-end incisal position to compensate for the procumbance of the lower incisors (Figure 5-12).



FIGURE 5-11 Intraoral view of bone plates modified to be used for skeletal traction.

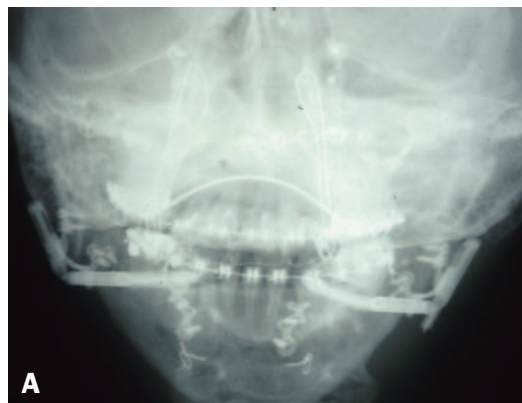


FIGURE 5-10 Posterior-anterior (A) and lateral (B) films shortly after surgery; note the skeletal wires in the maxilla and additional bone plates in the lower arch.

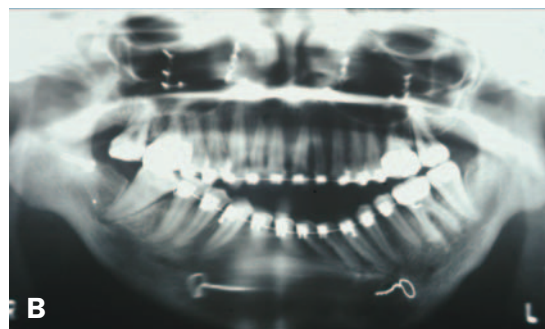
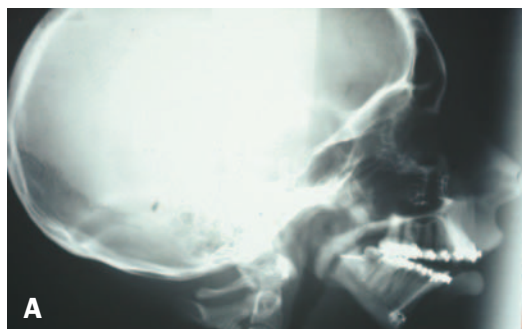


FIGURE 5-9 Lateral cephalogram (A) and panorex (B); note the severe deficiency and small condyles.

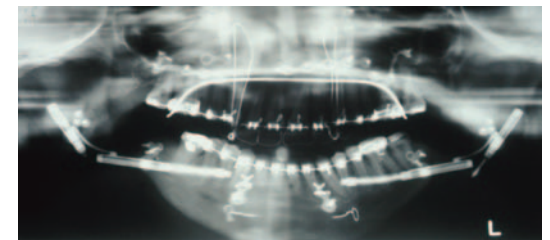


FIGURE 5-12 Lateral cephalogram (A) and panorex (B), with the mandible overcorrected; note the bone fill in the distraction sites.

Following the period of distraction, it was noted that she had a cross-bite and an open bite on the left side (Figure 5-13). These were addressed by orthodontics, initiated when the distraction was discontinued. The internal distractors were left in place for 6 months. When they were removed, she had a 10 mm augmentation genioplasty done (Figure 5-14).

Maxilla

Even with rigid fixation, instability of the maxilla is noted when the maxilla is advanced beyond 7 mm.^{24,25} This is particularly true when patients with previously repaired cleft lips and palates are treated.²⁶⁻²⁸ Polley and Figueroa have published extensively on distraction of the maxilla using external devices.²⁹ Modifying the level of the osteotomy can change the esthetic results. The external distractor system has a tooth-borne component and an external component (Figure 5-15). Moving the external distractor along an external rod can modify the vector of movement (Figure 5-16). Furthermore, the internal tooth-borne appliance can be modified by incorporating an expansion appliance to expand the maxilla (see Figure 5-15). The procedure is predictable but requires that the patient wear an external framework for 3 months and frequently a removable facemask for an additional 3 months at night. Intermaxillary elastics can be used during the period of distraction to modify the primary vector

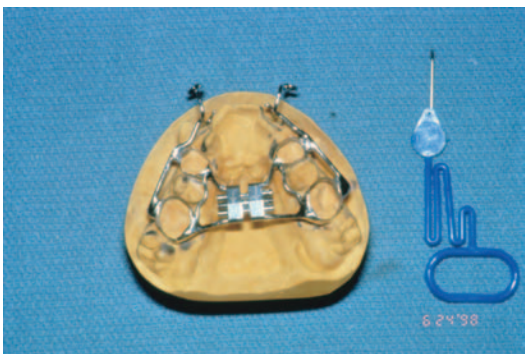


FIGURE 5-15 Tooth-borne appliance on model, with the expansion appliance incorporated into the framework.



FIGURE 5-16 Right (A) and left (B) lateral views, with appliance in place; note the downward traction with the external appliance.



FIGURE 5-13 A, B, Intraoral view, with occlusion overcorrected, and open bite on the left.

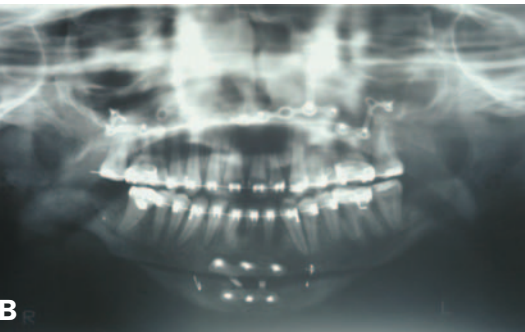
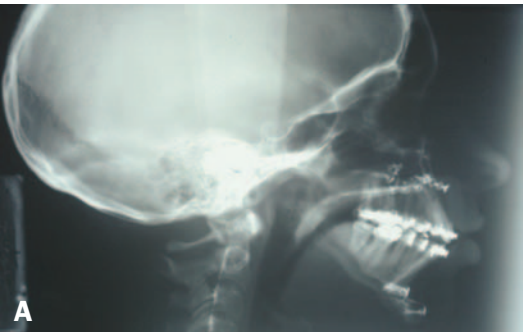


FIGURE 5-14 A, Lateral cephalogram and, B, panoramic radiograph with the genial segment advanced.

of movement. The maxilla of the patient in Figure 5-17 was advanced 11 mm and the maxillary midline was shifted to the left.

Internal bone-borne appliances have not been used as extensively as external distractors with tooth-borne appliances. Additionally, there is minimal ability to modify the bone cuts because of the necessity to place appliances on the maxilla or zygoma. Kebler and colleagues discussed the use of an internal bone distractor on four cases where they were able to advance a significant portion of the midface with the maxilla.³⁰ The patient in Figure 5-18 had a repaired unilateral cleft lip and palate. She had two separate operations in the posterior pharyngeal region in an

attempt to improve the nasal quality to her speech. From the preoperative cephalometric tracing and mounted models, it was determined that she would need a primary vector that was forward and down. Secondary vector control would be accomplished by intermaxillary elastic traction during or shortly after the period of distraction. Surgery was accomplished as a standard Le Fort I osteotomy. Prior to the osteotomy, care was taken to place the distractors in the desired vector of distraction. The distractors were removed and she underwent a full downfracture of the maxilla. The distractors were replaced and the maxilla was advanced to ensure that the appliances would work and then it was returned to her preoperative position. Following a 7-day latency period, she underwent distraction of 1 mm per day with a twice-a-day rhythm. Her maxilla was advanced 8 mm (Figure 5-19). Following the completion of distraction, orthodontics was immediately started. The distractors were left in place for 6 months (Figure 5-20). Interestingly, she had limited opening despite physiotherapy, which did not resolve until the distractors were removed.

The patient in Figure 5-21 is also a cleft lip and palate patient. She had a pharyngeal flap and a significant maxillary deficiency. Prediction

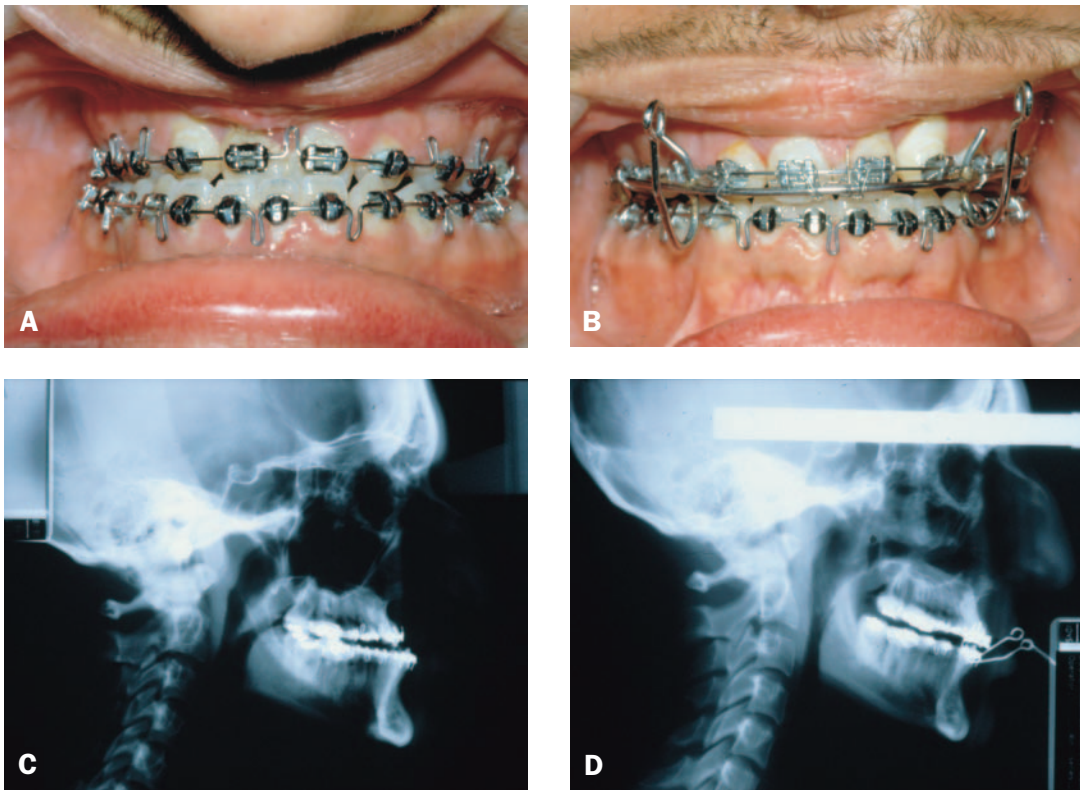


FIGURE 5-17 Intraoral preoperative (A) and postoperative (B) frontal films. Preoperative (C) and postoperative (D) lateral cephalometric films.

tracing and model surgery suggested that she would benefit from a 16 mm maxillary advancement (see Figure 5-21). Similar to the previous case, this patient had a Le Fort I osteotomy done in an operating room with the placement of internal distractors. At the time of surgery, an attempt was made to distract her maxilla the entire distance 16 mm. It was noted that her pharyngeal flap was very tight and appeared blanched. Her maxilla was returned to its preoperative position. She had a 6-day latency period and then underwent advancement at 1 mm per day with a twice-a-day rhythm (Figure 5-22). The flap did not appear to restrict the movement during the course of therapy. Her postoperative course was much more complicated than the patient in Figures 5-18 through 5-20. Because of her limited ability to follow instructions, on several occasions it was found that her appliance had not been activated as planned. This necessitated multiple postoperative visits. She is currently in therapy with the distractors in place (Figure 5-23).

Summary

Distraction osteogenesis has presented surgeons who treat patients with dentofacial and craniofacial deformities with a new tool. As in the case with intraarch segmental distraction, it offers

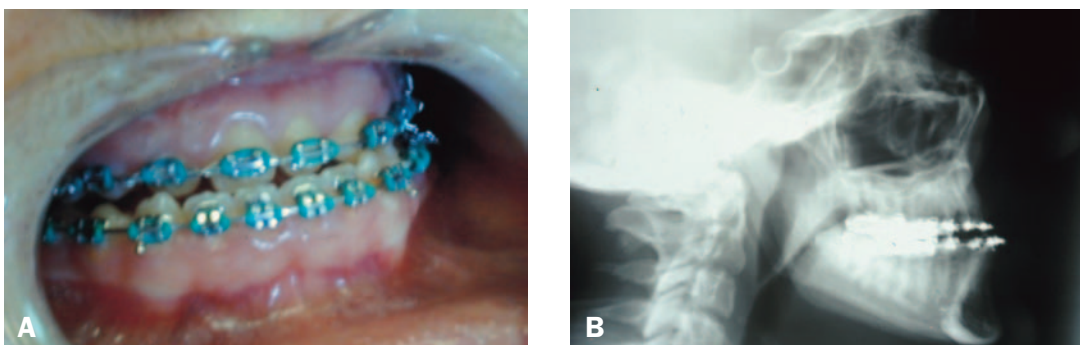


FIGURE 5-18 Intraoral (A) and lateral (B) cephalograms.



FIGURE 5-21 Preoperative lateral cephalogram; 16 mm discrepancy.



FIGURE 5-19 Postoperative cephalogram.

FIGURE 5-20 Intraoral frontal view. The distractors were maintained for 6 months.



FIGURE 5-22 Distractors in place.



FIGURE 5-23 Lateral cephalogram; approximately 10 mm of advancement was achieved over a 30-day period.

opportunities to treat combinations of dental crowding and skeletal discrepancies in one procedure or as a staged procedure. For large skeletal discrepancies, it appears to offer greater stability than that seen with traditional osteotomies. However, the occlusal results do not seem as predictable as that achieved with orthognathic techniques. In addition, it requires close monitoring of patients. Patient compliance plays a greater roll than in traditional orthognathics in the ultimate outcome of the procedure.

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Three-Dimensional Virtual Approach to Diagnosis and Treatment Planning of Maxillofacial Deformity

Gwen R. J. Swennen and Filip Schutyser

... Once a paradigm shift has occurred, a veritable explosion of new ideas and information leads to rapid advances in the field ...

Thomas S. Kuhn: The structure of scientific revolutions, 1996 Chicago

Accurate diagnosis and treatment planning are the keystones to obtaining facial balance and harmony and correction of the skeletal deformity, and to achieving a correct dental occlusion in patients with maxillofacial deformity. During the twentieth century, major breakthroughs were realized with the introduction of cephalometric radiography, orthodontics, maxillofacial osteotomies, osteosynthesis, and distraction osteogenesis, which have led to fundamental concepts on diagnosis and treatment planning of patients with maxillofacial deformity. These concepts, however, were primarily focused on the correction of the occlusion and skeletal deformity, with less emphasis on soft tissue aspects and facial esthetics. At the beginning of the twenty-first century, new paradigm shifts have been reshaping these fundamental concepts. The “soft tissue paradigm,” already introduced by Ackerman and colleagues in 1992, deemphasizes the value of cephalometric radiography and primarily focuses on the clinical examination with soft tissue considerations in order to obtain facial esthetics.^{1,2} Indeed, since its introduction in the early 1930s by Broadbent in the United States and Hofrath in Germany, generations of clinicians have relied far too much on cephalometric radiography for diagnosis, treatment planning, long-term follow-up of growth, and treatment outcome of patients with maxillofacial deformity.^{3,4} Although cephalograms are certainly valuable tools, their major drawback is their two-dimensional (2D) representation of a three-dimensional (3D) structure and that they do not provide in-depth visualization.

Three-dimensional imaging has meanwhile become an essential tool in planning and

managing the treatment of complex maxillofacial deformities. Recent advances in both computer hardware and software have enabled the introduction of the “3D virtual visualization paradigm,” which will have a major impact on the diagnosis and treatment planning of routine patients with maxillofacial deformity, and which will be complementary to the “soft tissue paradigm.” Different 3D imaging acquisition techniques have been developed and allow unprecedented 3D virtual diagnosis of maxillofacial deformity. The 3D virtual scene approach allowed the development of new 3D virtual tools for diagnosis, treatment planning, and evaluation of treatment outcome. The “3D virtual visualization paradigm” allows one to set up a virtual treatment goal and to compare, in an unprecedented objective way, the pretreatment status, treatment goal, and outcome. The introduction of 3D cephalometry of hard and soft tissues has bridged conventional cephalometric radiography with modern 3D imaging techniques, but it also has the potential to interact the “soft tissue paradigm” with the “3D virtual visualization paradigm.”⁵ The primary goal in the treatment of dentofacial deformity is a balanced face with normal soft tissue proportions, and adaptation with a functional occlusion knowing that the ideal soft tissue proportions define the ideal underlying hard tissue relationships.²

The 3D virtual cephalometric approach presents a powerful tool, because it provides high-quality in-depth visualization of the soft tissues and underlying hard tissues based on a single computed tomography (CT) data set. Moreover, it provides accurate and reliable quantitative soft tissue, hard tissue, and bone-related soft tissue

relationship data. Therefore, 3D cephalometry is expected to allow one to focus the treatment plan on the most ideal hard and soft tissue proportions and relationships within the individual limits of adaptation of the soft tissue facial mask and to avoid the mistake of the conventional cephalometric era that focused planning on ideal normative cephalometric values.

The introduction of cone-beam CT (CBCT) will probably be the key in the near future to an integrated 3D virtual approach toward routine diagnosis and treatment planning of maxillofacial deformity. Recent advances in CBCT technology allow vertical scanning of the patient in the natural head position (NHP), with reduced radiation exposure. Moreover, CBCT offers unique accessibility because of its low costs and the potential of in-office imaging in orthodontic and surgical outpatient clinics and private practices, owing to its compact design.

Although initial resistance by clinicians is normal, rapid advances in the field of 3D imaging will bring new findings, insights, and concepts. It is just the beginning of a new era and much needs to be developed and validated. It is essential to keep in mind that the “3D virtual visualization paradigm” remains a tool that will not replace the clinical examination of the patient.

The primary aim of this chapter is to provide a comprehensive overview on the available 3D image acquisition techniques and tools toward an integrated 3D virtual approach for diagnosis, treatment planning, and evaluation of treatment outcome of maxillofacial deformity, based on the current status of knowledge. This chapter, however, also intends to stimulate clinicians and researchers to extend their expertise and to

further develop this rapidly expanding field in order to move science forward. In a time of evidence-based medicine and dentistry, it will be crucial to validate these new approaches in prospective randomized control trials in order to translate valid research into the clinical routine for better high-quality care of the patient with maxillofacial deformity.

Three-dimensional Imaging

In order to create an integrated 3D virtual approach toward diagnosis, treatment planning, and evaluation of treatment outcome of maxillofacial deformity, an appropriate anatomic model of the head and a suitable “3D virtual visualization paradigm” have to be established. The first step toward such a model is an appropriate acquisition of the patient’s anatomy. The currently available 3D image acquisition techniques for capturing the 3D shape of the head are described below. It is illustrated how all acquired data can be composed to a digital 3D virtual augmented model of the head. Finally, a 3D virtual scene approach is described that allows presentation of these data in an interactive way on the computer screen to allow virtual diagnosis and treatment planning of the patient with maxillofacial deformity.

Three-dimensional Image Acquisition Techniques

To build a virtual anatomic model of the head of the patient, various 3D image acquisition techniques are available. From CT or magnetic resonance imaging (MRI) scans, a volumetric data block is obtained. Next to volumetric data acquisition, 3D surface information can also be acquired. Several approaches to digitize a surface and their applications to image the head are described below.

Volumetric Imaging

As a result of volumetric imaging, image volumes of the patient’s anatomy are acquired. This data block is built by data points aligned in a 3D grid. The basic building block of this grid holding a data sample, such as the CT number, is called a voxel. In dentofacial and craniomaxillofacial imaging, CT and MRI are often applied. In the future, 3D ultrasonic imaging of the head is expected to be introduced as well.

For digital transmission of medical imaging data, a dedicated open communication protocol has been established: digital imaging and communication in medicine (DICOM, NEMA, Rosslyn, VA). DICOM also specifies the file format for storage of the medical image data on a CD. Typically, a picture archiving and communication system (PACS) organizes storage and retrieval of medical data. In the digital era and in a time

of evidence-based medicine, image information therefore provides a strong medicolegal record, because the original DICOM files are archived and can always be retrieved.

Computed tomography. Computed tomography is an imaging modality that produces cross-sectional images representing the x-ray attenuation properties of the body. Single-slice spiral CT was introduced in 1989 (Figure 6-1A), and this technology has undergone a major evolution since 1998. On the one hand, the multi-slice CT scanner was introduced, and has replaced the single-slice CT scanner in almost all radiologic departments.⁶ The second evolution was the emergence of the CBCT apparatus, specifically designed for imaging the maxillofacial complex within the setting of an orthodontic or surgical outpatient clinic or private practice.

Multi-slice computed tomography. Multi-slice CT (MSCT) scanners allow fast high-quality imaging. Nowadays, 2- to 64-slice CT scanners are available (Figure 6-1B), which shortens the acquisition time. To image the head with a high image quality, an x-ray tube voltage of 120 kV and an effective tube current of 80 mA are recommended. The pitch (calculated as feed per rotation over total slice collimation) is preferable lower than 1 (eg, 0.75). For a scan from the chin up to the frontal sinus, the effective radiation dose is about 0.41 mSv. This corresponds to 50 days of natural background radiation. A reconstruction interval of 0.75 mm is sufficient for 3D cephalometry and 3D image-based planning.⁷ Recent research has shown that dose reduction by a decrease of the effective tube current to 40 mA (effective radiation dose of about 0.20 mSv) is acceptable (J. Casselman, personal communication, November 2005).

If the patient has amalgam fillings, dental restorations, or crown and bridgework, then streak artifacts occur. To minimize the number of slices affected by streak artifacts, the occlusal

plane of the patient should coincide with the axial slices. During CT scanning, it is important that patients close their mouth with their normal natural occlusion. If the patient can lie still during CT scanning, then no fixation bandages should be used, to avoid extra soft tissue deformations. Because of the lying position, the patient’s head is not in the NHP, which remains an important disadvantage of multi-slice CT.

Cone-beam computed tomography. With cone-beam CT, the x-ray beam is cone shaped, and the detector is a flat 2D surface (Figure 6-1C). With this technology, specific systems for imaging the maxillofacial complex are constructed. These systems allow in-office imaging in orthodontic and surgical outpatient clinics and private practices because of their compact design. With dedicated cone-beam reconstruction algorithms, a detailed image volume is computed.⁸ In 1998, the first CBCT scanner in the maxillofacial field was commercialized. In 2002, a new design of the scanner was released that allowed imaging of patients while they were being seated. Also a first, a system with a flat-panel detector instead of an image intensifier was commercialized.

Since CBCT works with very low tube currents, and pulsed x-ray beams, the effective radiation dose is very low. For NewTom9000, NewTom3G, and i-CAT (20 sec scan), effective radiation doses of 0.050 mSv, 0.056 mSv and 0.068 mSv, respectively, have been reported, according to the International Commission on Radiological Protection’s Publication Number 60.^{9–13} More advantages of CBCT are obvious. Because of its ability to scan the patient in a sitting position, image capture of the patient’s head in its NHP becomes possible. The artifacts at the level of the occlusion are less important. Moreover, CBCT offers unique accessibility because of its low costs compared with MSCT and the potential of in-office imaging. CBCT has already made major contributions to maxillofacial imaging.^{14–23}

A current limitation of CBCT for imaging of the head is the scanning volume. The imaged volume is dependent on the shape of the x-ray beam and the size of the detector. Furthermore, CBCT has no absolute Hounsfield units (HF). The HF of the same tissue changes between scans and with the position of that tissue in the field of view of the scanner. Several improvements in this field are expected in the near future.^{20,24}

Magnetic Resonance Imaging. Magnetic resonance imaging exploits the physical phenomenon of nuclear magnetic resonance to measure the magnetic property of tissue. An obvious advantage of this modality is the absence of harmful radiation. With the appropriate

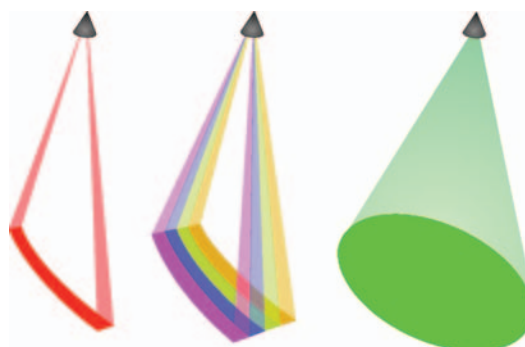


FIGURE 6-1 Three types of computed tomography (CT) scanners are currently distinguished: single-slice CT (A), multi slice (MS) CT (B), and cone-beam (CB) CT (C).

acquisition sequences, different soft tissues can be distinguished. However, detailed imaging of the (cortical) bone remains difficult.

A typical application of MRI in maxillofacial imaging is the assessment of temporomandibular joint (TMJ) abnormalities. The standard imaging protocol consists of oblique sagittal and oblique coronal images of the TMJ that are obtained perpendicular to or parallel to the long axis of the mandibular condyle, to visualize disk position and morphology as well as the bone structures.²⁵

Segmenting the skull from MRI is not straightforward. From T1-weighted images, it is hard to manually delineate the bone contours (Figure 6-2). Proton density (PD) images,

however, give more contrast to see the bone boundaries. Early attempts for automatic segmentation of the skull are described in the literature.^{26,27} The process typically concerns segmentation of the cranium as a by-product of segmenting the white and gray brain matter and cerebrospinal fluid, or to simulate the behavior of electromagnetic fields in the head, or model the electrical activity of the cortex. Segmentation results of the maxillofacial complex are poor. A lot of fundamental research on MRI and image analysis is still required to make some progress. Therefore, currently, CT is the modality of preference to image the patient's skull.

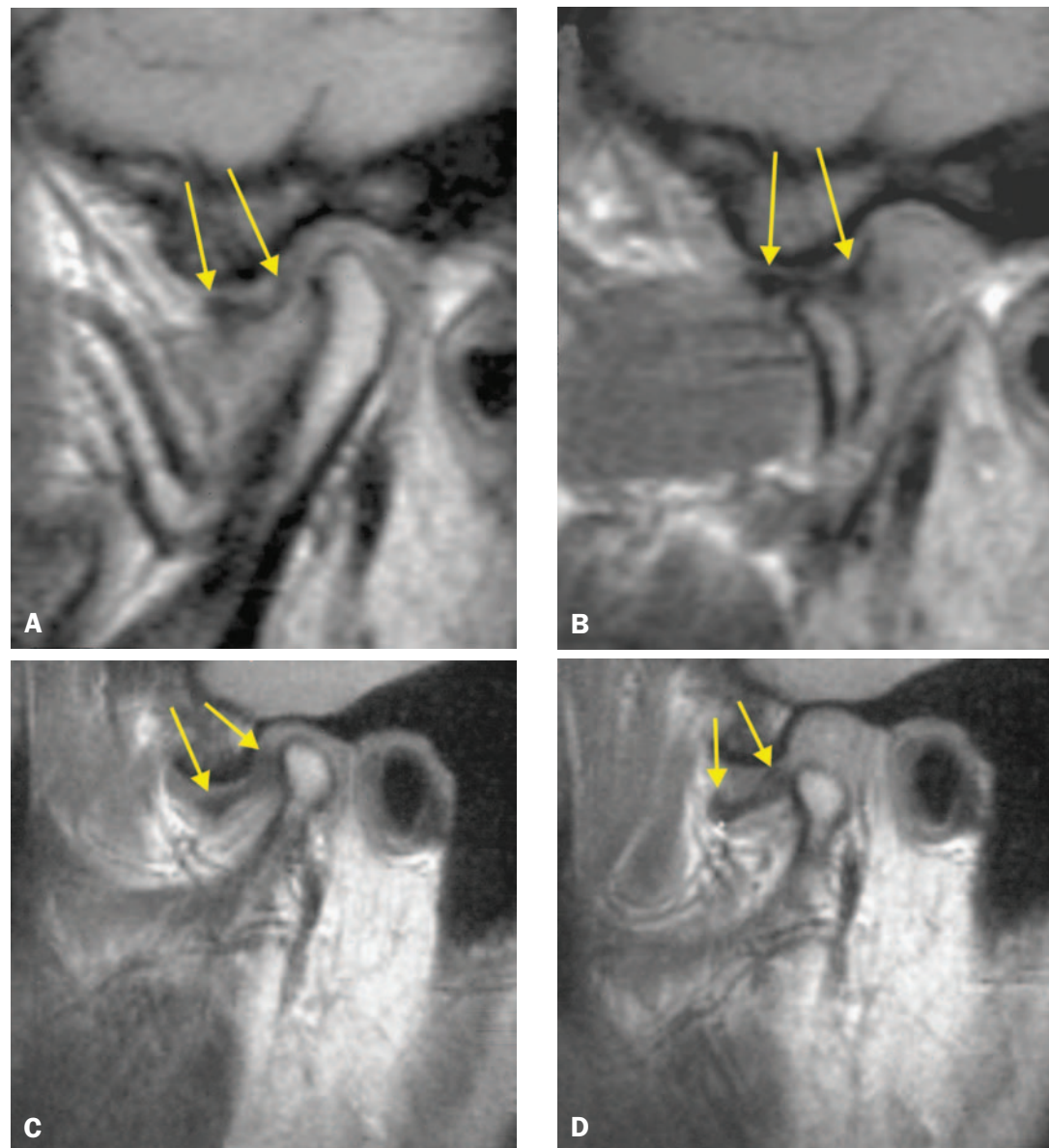


FIGURE 6-2 Parasagittal T1-weighted spin echo images of two patients. The disk (arrows) is anteriorly displaced relative to the condyle in closed-mouth position (A), but when the patient opens the mouth, the disk is reduced to its normal position relative to the mandibular condyle (B). The disk of a second patient is anteriorly displaced relative to the condyle in closed-mouth position (C). This patient is not able to open the mouth completely, as the condyle fails to pass below the disk (D). This is called “closed lock.” Reproduced with permission from Prof. R. Hermans, Department of Radiology, UZ Leuven, Belgium.

Surface Acquisition Systems

In addition to volumetric acquisition systems, several surface acquisition systems are available that sense and reconstruct a surface. Surface acquisition systems produce a textured 3D surface defined by a large collection of triangles. The currently available surface acquisition techniques and their applications are described below.

Laser Surface Scanning. With laser surface scanning, a laser spot or line is swept along the object to be imaged. When scanning the skin of the face, a safe low-intensity laser is applied. The system shines this laser on the face to create a lighted profile. A high-quality video sensor captures this profile from two viewpoints. The system can digitize thousands of these profiles in a few seconds to capture the shape of the entire object (Figure 6-3). Additionally, a second video sensor can acquire color information, which is added to the surface.

This technology is also applied to digitize dental casts or impressions. A laser line is moved along the dental arch, and a surface model is constructed.

Laser surface scanning produces very accurate models. It is also possible to image the entire head in one scan. However, the scanning takes several seconds, which is a challenge for facial imaging, especially with young children. Another disadvantage is that undercuts are not imaged correctly, since the laser light is following a straight path.

Probe Scanning. With probe scanning, an object is meticulously sensed by a computer controller probe. Obviously,



FIGURE 6-3 High-resolution full-face color surface model of Patient F.S., acquired with a commercial three-dimensional surface imaging system (3dMDface system, 3dMD, Atlanta, GA) based on active stereo photogrammetry.

it is not possible to acquire the shape of a face, but hard surfaces such as dental casts are digitized with an accuracy of a few microns (μm). The scanning process is quite slow, and the scanned object cannot have any shape.

This type of scanner can be applied for scanning the impression to perform computed-aided design (CAD) of a crown.

3D Structured Light Photography and 3D Stereo Photography

A third technology family builds a surface based on 2D photographs. Within this family, two approaches are possible, and they can also be combined. As a result, a textured skin surface is obtained.

A first possibility is projecting a pattern on the patient's face, and simultaneously acquiring one photograph. Based on the deformation of the pattern, depth information is computed. This is 3D structured light photography. Typically, several photographs are needed to image the object completely. Solutions with a sequence of patterns are also available, thus increasing the robustness of the system.

A second possibility requires at least two (simultaneous) photographs of the same object acquired from different viewing angles. No pattern is projected. The corresponding points are searched, and from this information, depth information is computed. This is 3D stereo photography.

The acquisition time is very short, which is favorable for face scanning. When several patterns are projected, the acquisition time is typically about 1 second. However, these systems are robust for small movements during acquisition.

The extent of the surface can be limited, or the number of photographs taken during acquisition has to be sufficiently high. Points that are not visible from the camera's viewpoint will also generate artifacts. This occurs typically at the nose and the ears. Furthermore, the accuracy is lower when compared with laser scanning or probe scanning, if one supposes that the scanned object is not moving.

Three-dimensional Virtual Augmented Head Model

The described variety of imaging modalities can be combined, since one imaging source is not sufficient to build a complete and accurate virtual anatomic head model. The basic imaging modality is CT, since volumetric data of the entire head are obtained. However, this information has to be augmented with the natural complexion of the skin, and a detailed imaging of the dentition is required.

From the CT image volume, surfaces are segmented. This requires binary segmentation; that is, a delineation of the structure of interest.

For example, a bone or skin surface can be automatically extracted from an MSCT image volume. However, the skin surface lacks color information, and the teeth surfaces are not detailed enough and may be disturbed because of imaging artifacts.

To fuse the information from another imaging source to the CT data, image registration is needed. With rigid registration techniques, a translation and rotation of one object is computed to make it coincide with a second object. There are three main methods for rigid registration. With point-based registration, the transformation is computed based on corresponding pairs of points.²⁸ A one-to-one correspondence in both sets of data is needed. With surface-based registration, the correspondence between two point clouds is searched, and from this correspondence the transformation matrix is computed.^{29,30} Finally, voxel-based registration uses all gray-value information of two image volumes to find the transformation matrix. Methods from information technology (maximization of mutual information) are applied to find the registration.³¹

To enhance the skin surface, the color information of the face is added. With rigid-surface registration, a 3D photograph of the patient is fused with the skin surface extracted from CT (Figure 6-4). Since the head position during CT scanning and surface scanning may differ, an additional nonrigid registration may be needed to deform the 3D photograph to the CT to obtain a consistent data set.³² It is quite obvious that the skin surface will differ if CT scanning is performed in the horizontal position and the 3D photograph is taken in the vertical position. Therefore, CBCT systems that allow vertical scanning of the head of the patient in its NHP are promising. It will

be crucial, however, to standardize the patient's NHP position during data recording with both techniques. Small differences in facial expression also badly influence the matching procedure. The texture information of the skin increases the reality of the visualization, and gives the possibility to include eyebrow and hairline information to the augmented model.

The imaging of the dentition can also be augmented. Highly detailed imaging of the dentition is necessary for diagnosis and treatment planning of maxillofacial deformity. However, the interocclusion relationship is often deteriorated by streak artifacts caused by radiolucent dental restorations (eg, amalgam) or orthodontic brackets. Moreover, the detail of the dental surfaces and intercuspitation is limited, owing to the resolution dose that should be as low as reasonably acceptable. Different attempts have been reported in the literature to integrate an accurate dental model into 3D milled, stereolithographic, and computerized models of the skull.³³⁻⁴¹

Conventionally, dental impressions are taken from the patient and transformed into plaster dental casts. These plaster dental casts or impressions can be surface scanned or CT scanned in order to obtain 3D digital dental models. Surface scanners offer a cheap solution for in-house scanning. However, undercuts may reduce the accuracy. With clinical CT, the scan parameters can be set up to have a high-accuracy scan with cubic voxels of about 0.2 mm. In addition, industrial CT scanners can be applied with a voxel size of about 127 μm , and smaller.

In the case of a CT scan of the dental models, an occlusal bite registration (3D splint) and a double-scan procedure are applied to relate the upper and lower dentitions in the correct way,

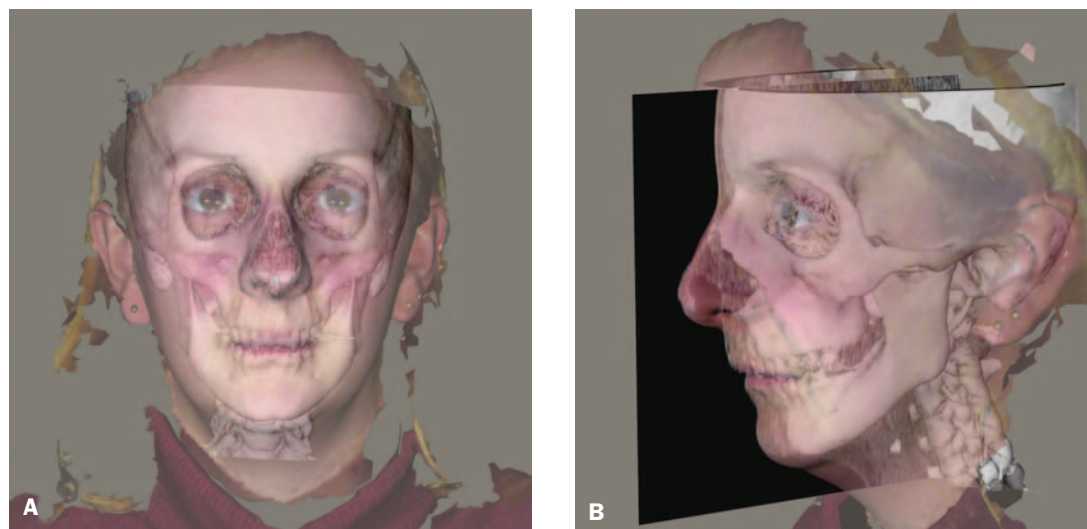


FIGURE 6-4 Model of Patient F.L. Once the surface scan (3dMDface System; 3dMD, Atlanta, GA; accessible at: <http://www.3dMD.com>) is registered with the computed tomography scan, both data sets can be visualized together (Maxilim, version 2.0, Medicim NV, Belgium).

and to fuse it with the patient's CT.^{40,41} This splint is equipped with radiopaque spherical gutta-percha markers. Based on these markers, automatic point-based rigid registration is applied to fuse both CT data sets. To avoid these markers being in the occlusal plane where CT artifacts may be expected, a 3D extension, either intra-orally or extra-orally, with markers is added. The patient wears this splint during CT scanning. The markers are extracted from the patient's scan and from the second scan (ie, the scan of the plaster model or impression), and one-to-one correspondences are found to compute the registration matrix.⁴⁰ In this way, the detailed information of the dentition is fused with the patient's CT scan (Figure 6-5).

Using this technique, the CT scan of the patient can be augmented with the natural complexion of the skin surface, and a detailed image of the dentition obtained. In order to use the virtual augmented model of the head for diagnosis and treatment planning of maxillofacial deformity, an appropriate "3D virtual visualization paradigm" is necessary, which is described below.

Three-dimensional Virtual Scene Approach

To visualize the data acquired from various 3D imaging sources, an appropriate "3D virtual visualization paradigm" is needed. Therefore, a scene-based approach is adopted. The virtual 3D space is considered as a 3D scene, with medical image data as actors. This scene is viewed with a virtual camera, and the resulting views of the camera are shown on the screen. To inspect the scene from various angles and positions, the camera is moved around in the scene to image the structures of interest.

A volume of voxels can be rendered with volume rendering. For each voxel, a color and opacity can be assigned. Next, a projection image according to the viewing direction of the virtual camera is computed and presented on a computer screen. Several shading algorithms for volume rendering are available. The advantage is that the transitions between several tissues are smooth, and beautiful images are obtained. However, this method is computationally expensive and therefore preferred for visualizing structures such as vessels in the head and neck region, and organs like the heart and lungs (Figure 6-6).

Another technology is surface rendering. Surfaces are drawn (rendered) on the computer screen given a viewing direction of the virtual

camera. The advantage is that high rendering speeds can be obtained on mainstream computer hardware. However, accurate segmentation is needed. With surface rendering, the results from surface-scanning hardware can be integrated in a straightforward way. Although mixing volume rendering and surface rendering is technically possible, this technology is still at an early stage.

Surface rendering is currently the preferred technique for diagnosis and treatment planning of maxillofacial deformity. Once the augmented head model is added to the scene, related data such as rulers, surgical devices, and markers compose the scene. Moreover, additional CT slices can be added to the scene (Figure 6-7). Landmarks can be indicated, virtual osteotomies can be performed, new bone fragment positions can be defined, and subsequent accurate soft tissue simulation will be possible in the future.

In order to bridge conventional cephalometric radiography with modern 3D imaging techniques, a new virtual approach to 3D cephalometry of hard and soft tissues was introduced (see next section, "Three-dimensional Virtual Approach to Diagnosis and Treatment Planning of Maxillofacial Deformity").⁵ The 3D virtual scene is extended with virtual lateral and frontal cephalograms that are computed from the CT data (Figure 6-8). The combination of the geometrically related virtual cephalograms with the hard and soft tissue surface representations allows accurate and reliable 3D cephalometric analysis.⁴² Each point landmark is visualized on the surface representations together with its projection points on the cephalograms. Depending on the nature of a landmark, it can be easily indicated on the virtual cephalograms or surface representations, and finally three-dimensionally

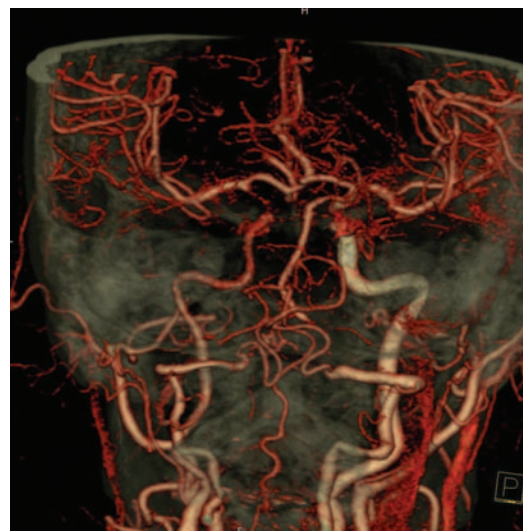


FIGURE 6-6 Volume rendering of the vessels in the head and neck region. The voxels belonging to the skull are rendered transparent. Reproduced with permission from Dirk Loeckx, K. U. Leuven, Belgium.

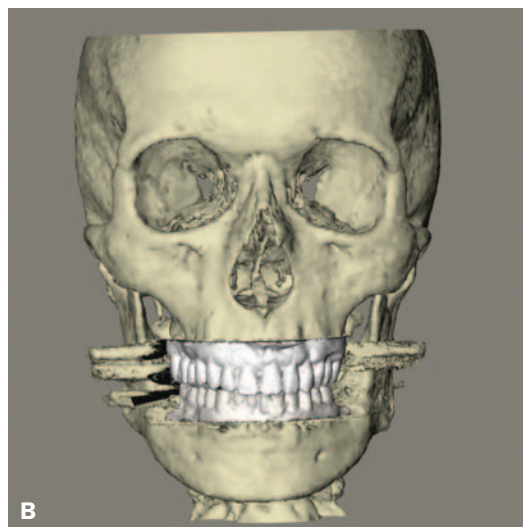
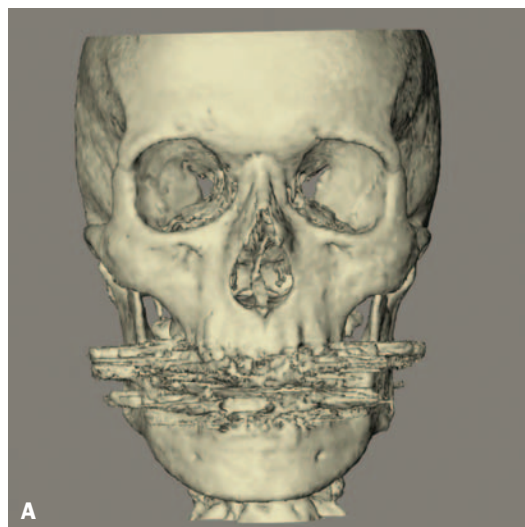


FIGURE 6-5 Streak artifacts may jeopardize the correct imaging at the level of the occlusion (A). With appropriate imaging and image fusion (Maxilim, version 2.0, Medicim NV, Belgium), the skull model is augmented with a detailed model of the dentition (B).

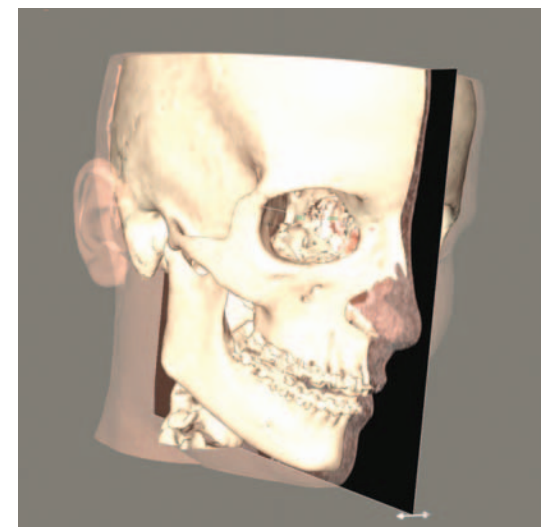


FIGURE 6-7 Surface rendering of the skull with semi-transparent facial soft tissues, and a sagittal reslice through the computed tomography volume (Maxilim, version 2.0, Medicim NV, Belgium).

adjusted on the hard or soft tissue surface representations. This ease of indicating landmarks is an important benefit of this approach. Once point landmarks are defined, they can be combined to define anatomic planes. Based on these landmarks and planes, a complete set of measurements can be defined: linear, orthogonal, angular, and proportional measurements. Both MSCT and CBCT imagings are suitable for the virtual 3D cephalometric approach.

Because it is important to be able to visualize only the structures of interest during diagnosis and treatment planning of maxillofacial deformity, all the objects in the scene have a visibility property. With this property, objects can be made temporarily invisible behind the object of interest and can be made visible again if needed.

Surface rendering is therefore perfectly suitable for 3D virtual diagnosis (3D cephalometry and 3D model analysis), 3D virtual treatment planning (3D virtual surgery and soft tissue simulation), and 3D virtual evaluation of treatment outcome, which will be described in the next section of this chapter.

Three-dimensional Virtual Approach to Diagnosis and Treatment Planning of Maxillofacial Deformity

Three-dimensional imaging, computer-aided design/computer-assisted manufacturing (CAD/CAM) techniques, and computer-assisted surgery (CAS) are becoming increasingly popular, and currently open new modalities in diagnosis and treatment planning of maxillofacial deformity.^{5,43-63}

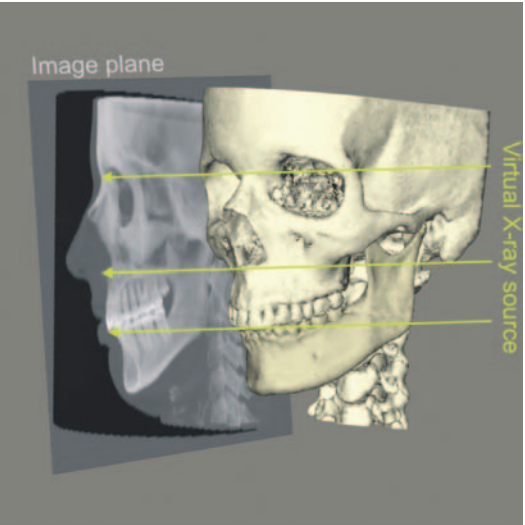


FIGURE 6-8 From the computed tomography image volume, a virtual cephalogram is computed. The software virtually sends an x-ray beam through the patient and the resulting x-ray image is visualized in a geometrically correlated way.

Conventional diagnosis and treatment planning of maxillofacial deformity involves clinical, cephalometric, and anthropometric examinations of the patient and the manufacturing of surgical splints based on plaster dental model surgery. In this section, the potential of an integrated 3D virtual scene approach toward diagnosis, treatment planning, and evaluation of treatment outcome of maxillofacial deformity, based on CT as a volumetric imaging method and 3D structured light (stereo) photography as a surface acquisition system, is presented.

Virtual Three-dimensional Diagnosis

Three-dimensional Cephalometry of Hard and Soft Tissues

Recently, a new virtual approach to 3D cephalometry of both hard and soft tissues was introduced and validated based on CT.^{5,42} In order to bridge conventional cephalometry with modern 3D imaging, virtual lateral and frontal cephalograms are computed from a single MSCT or CBCT data set and linked with both hard and soft tissue 3D surface representations.²⁴ The step-by-step virtual scene approach to 3D cephalometry is summarized in Table 6-1.

The first step of the 3D virtual cephalometric approach consists of rendering the segmented hard and soft tissue surface representations of the skull in the virtual scene, which allows high-quality real-time inspection of the patient's anatomy (Figure 6-9).

The next step consists of virtual positioning of the skull in a standardized position, orientated to the median plane using paired anatomic normal midfacial structures (eg, the orbits, frontal process of the maxilla, frontozygomatic suture) and the right Frankfort horizontal (FH) plane (step 2) (Figure 6-10). In unilateral congenital or acquired malformations, the nonaffected FH should be used, whereas in bilateral malformations, one should make an effort to orient the skull parallel to the FH using other nonaffected anatomic landmarks. With the introduction of CBCT scanners that allow vertical scanning of

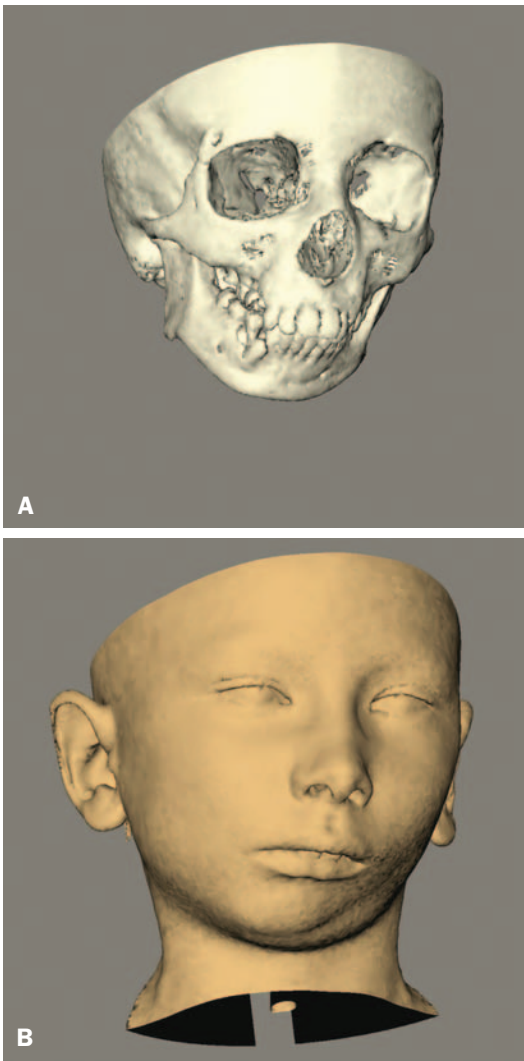


FIGURE 6-9 Multi-slice computed tomography scan of Patient B.R. Three-dimensional (3D) hard (A) and soft (B) tissue surface representations of a 9-year-old female patient with mandibular asymmetry in the 3D virtual scene (step 1). The mandibular asymmetry was caused by loss of the right condylar process in early infancy, attributed to an episode of malignant external otitis (MEO) with severe temporomandibular joint involvement. At the age of 9 years, she presented with a decreased right vertical ramus length, a chin deviation to the right, and a canted occlusal plane. She had limited and painful mouth opening due to trismus.

Table 6-1 Step-by-Step Virtual Scene Approach to Three-Dimensional (3D) Cephalometry		
Step 1	Rendering of DICOM data into the 3D viewer	Automated
Step 2	Standardized virtual positioning of the skull	Semi-automated
Step 3	Computing and linking of virtual lateral and frontal cephalograms to the 3D hard and soft tissue surface representations	Automated
Step 4	3D definition of the nasion (N) and sella (S) landmarks	Manual
Step 5	Set-up of the 3D anterior cranial base (S-N) plane	Automated
Step 6	Set-up of the 3D anatomic Cartesian cephalometric reference system	Automated
Step 7	Definition of 3D cephalometric hard and soft tissue landmarks	Manual
Step 8	Definition of 3D cephalometric planes	Automated
Step 9	3D cephalometric hard and soft tissue analysis	Automated

Note that with cone-beam computed tomography 3D cephalometry, the patient is positioned in the natural head position during record taking.
DICOM = Digital Imaging and Communication in Medicine.

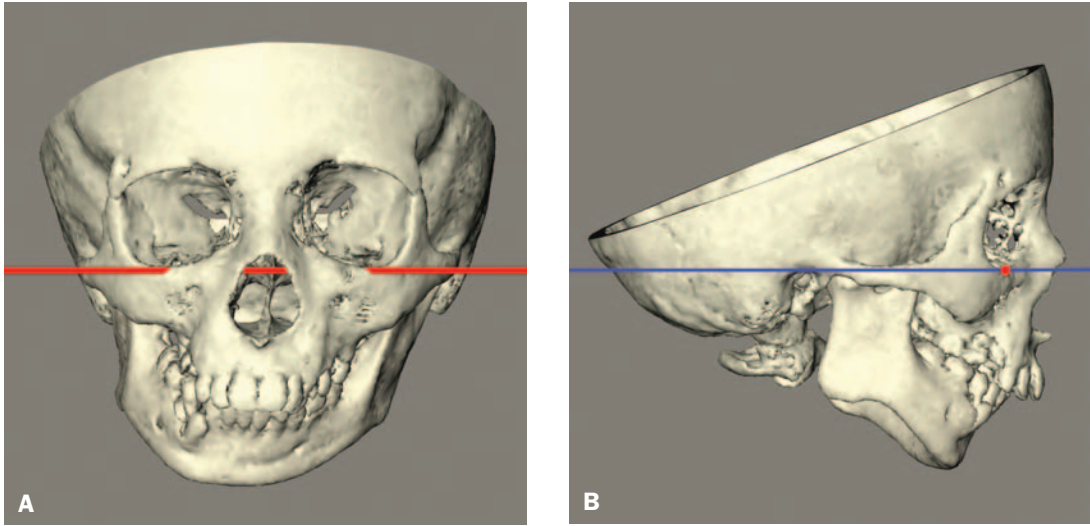


FIGURE 6-10 Multi-slice computed tomography scan of Patient B.R. Semi-automated standardized positioning of the patient in the virtual scene orientated to the median (A) and right Frankfort horizontal (FH) plane (B) (step 2) (Maxilim, version 2.0, Medicim NV, Belgium).

the patient in the NHP, this step could be avoided once record taking during CBCT is standardized (Figure 6-11).

Virtual lateral and frontal cephalograms are now automatically computed as orthogonal projections from the CT data set and linked to the 3D hard and soft tissue surface representations of

the skull using virtual reality techniques (step 3) (Figure 6-12).

To allow diagnosis, treatment planning, and evaluation of treatment outcome of maxillofacial deformity, a precise and reproducible 3D reference system is required. Especially for evaluation of treatment outcome during growth,

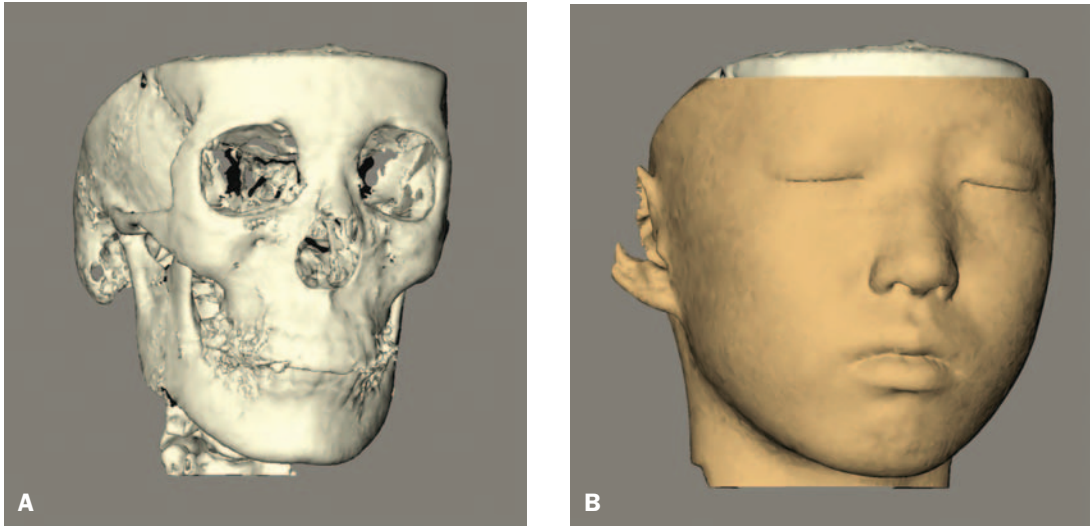


FIGURE 6-11 Three-dimensional hard (A) and soft (B) tissue surface representations of a patient scanned in natural head position (CB MercuRay Cone-Beam Computed Tomography; Hitachi Medical Corporation, Japan). CBCT dataset courtesy of Dr. R. Kanomi Dental Clinic, Himeji, Japan.

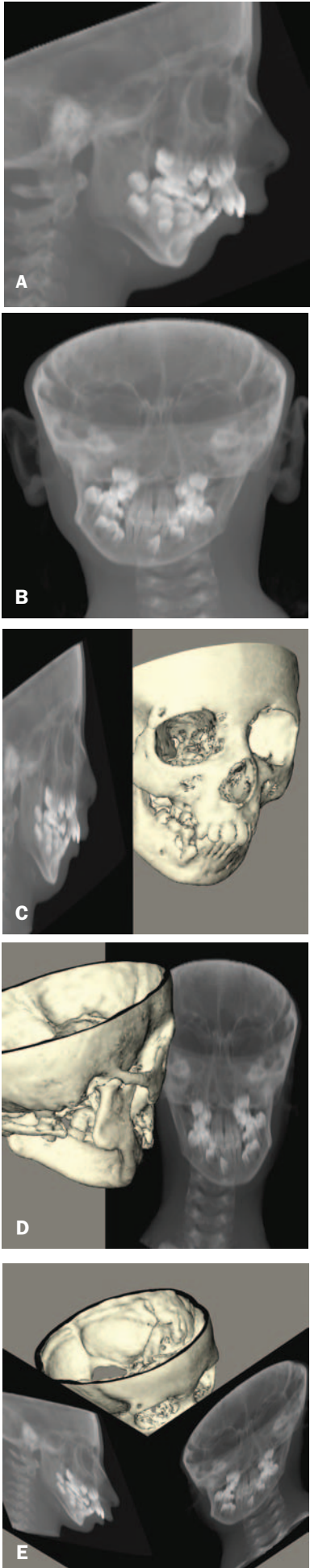


FIGURE 6-12 Multi-slice computed tomography scan of Patient B.R. Virtual lateral (A, C) and frontal (B, D) cephalograms automatically computed as orthogonal projections from the single computed tomography data set and linked (E) to the three-dimensional hard tissue surface representation (step 3) (Maxilim, version 2.0, Medicim NV, Belgium).

an anatomically meaningful 3D reference system is necessary. Rigid voxel-based registration (see subsection “Rigid Registration,” below) during growth is highly sensible to analysis bias because the subvolume of the skull, which is likely to be the most stable during growth, is currently not known. In conventional radiographic cephalometry, different anatomic reference systems have been proposed and controversially discussed. The set-up of the Cartesian 3D cephalometric reference system in this particular 3D cephalometric approach was based on the reference system, advocated by Profitt and colleagues, in conventional cephalometry with the horizontal plane 6° below the sella–nasion (S–N) line.⁶⁴ Hence, the next step consists of 3D definition of the nasion (N) and sella (S) landmarks (Figures 6-13 and 6-14). The combination of the

virtual lateral cephalogram with the 3D hard tissue surface representation is the key for easy, accurate, and reliable definition of those landmarks (step 4).⁴² Once the latter skeletal landmarks are defined, the anterior cranial base (S–N) plane is automatically computed from the available geometric information (step 5) (Figure 6-15). In the next step, the 3D anatomic Cartesian reference system, centered in sella, is automatically computed. The horizontal 3D cephalometric

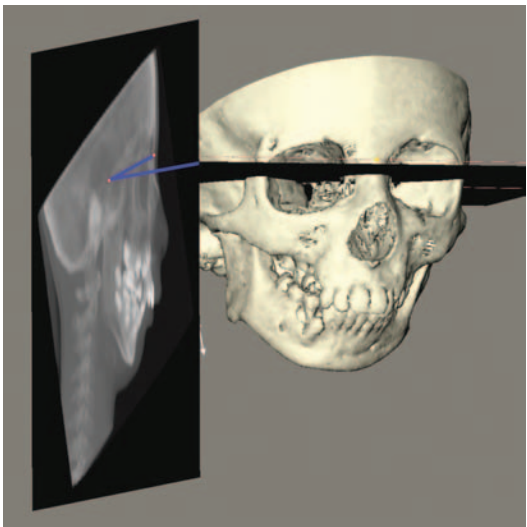


FIGURE 6-15 Multi-slice computed tomography scan of Patient B.R. Set-up of the anterior cranial base plane (step 5) (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>).

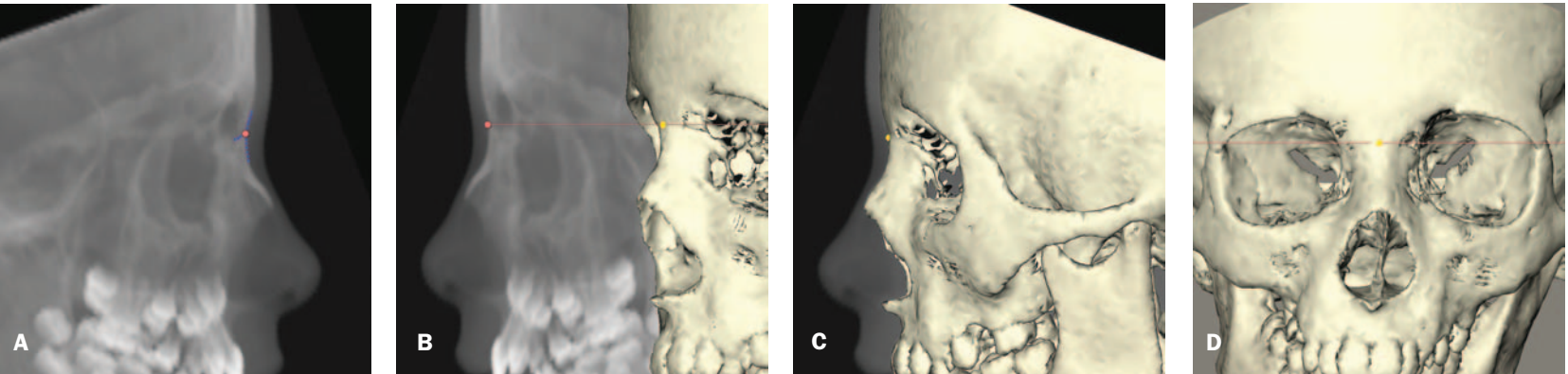


FIGURE 6-13 Multi-slice computed tomography scan of Patient B.R. Three-dimensional (3D) definition of the nasion landmark (step 4). The nasion landmark is first defined on the virtual lateral cephalogram in the same manner as is done in conventional cephalometry (A). The 3D virtual scene approach links the position of the nasion landmark to the 3D hard tissue surface representation (B, C) on which the midline position of the nasion landmark is corrected (D) (Maxilim, version 2.0, Medicim NV, Belgium).

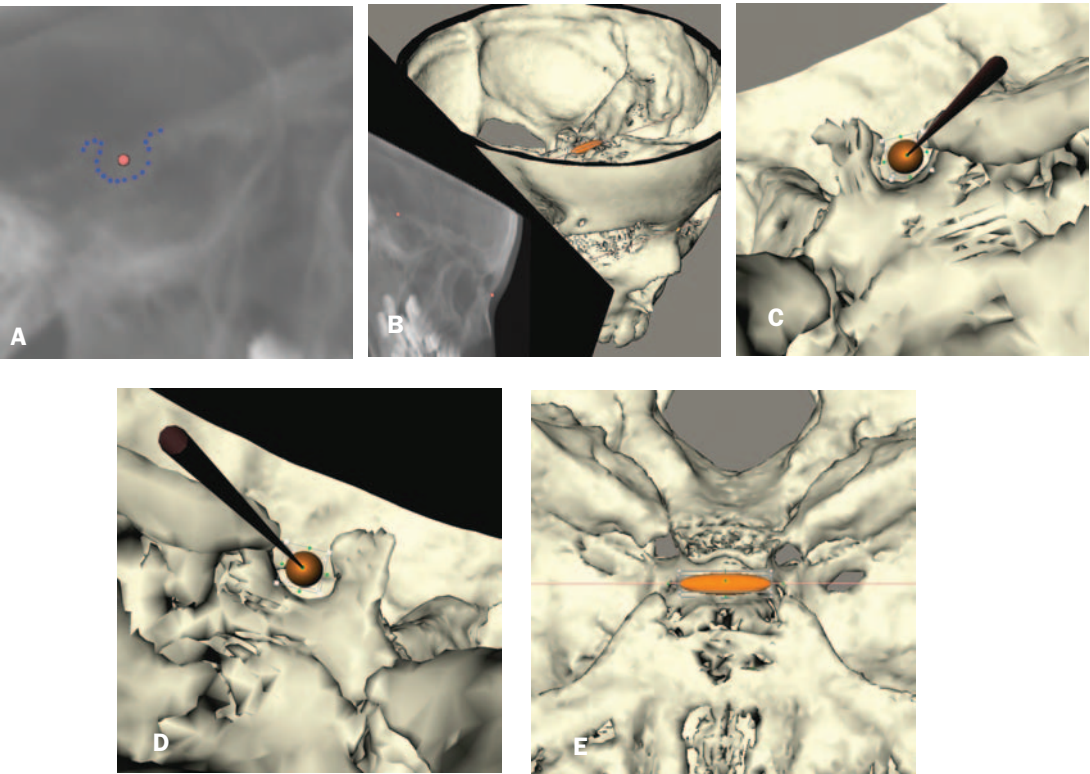


FIGURE 6-14 Multi-slice computed tomography scan of Patient B.R. Three-dimensional (3D) definition of the sella landmark (step 4). As with the nasion, the sella landmark is also first defined on the virtual lateral cephalogram as is done in conventional cephalometry (A). The 3D virtual scene approach links the position of the sella landmark to the 3D hard tissue surface representation and allows 3D virtual navigation into the endocranial skull base. For precise and reproducible 3D definition of the sella landmark, a virtual ellipse tool was developed, which can be fitted individually into the hypophyseal fossa. The center of this virtual ellipse defines the sella landmark (Maxilim, version 2.0, Medicim NV, Belgium).

reference plane (x-plane) is generated in sella, 6° below the 3D S–N plane, and consecutively, the vertical (y-plane) and horizontal (z-plane) 3D cephalometric reference planes are automatically computed (step 6) (Figures 6-16 through 6-19).

The keystone of the presented 3D virtual cephalometric approach is the computing of

virtual lateral and frontal cephalograms from a single CT data set that are linked to the 3D hard and soft tissue surface representations in a geometric way. This approach allows precise and reproducible definition of 3D cephalometric hard and soft tissue landmarks, automatic set-up of 3D cephalometric planes, and 3D cephalometric hard

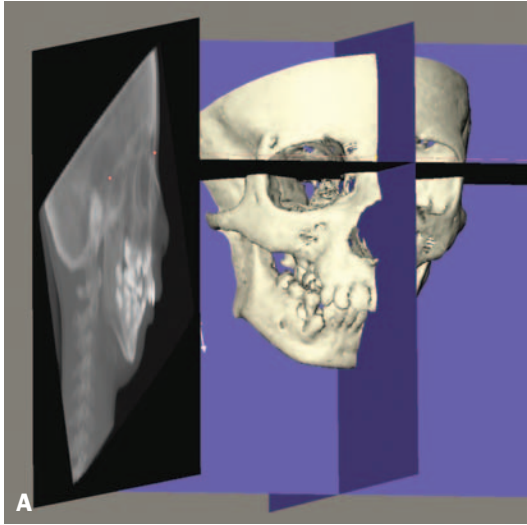


FIGURE 6-16 Multi-slice computed tomography scan of Patient B.R. Set-up of the three-dimensional anatomic Cartesian reference system centered in the sella (step 6) (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>).

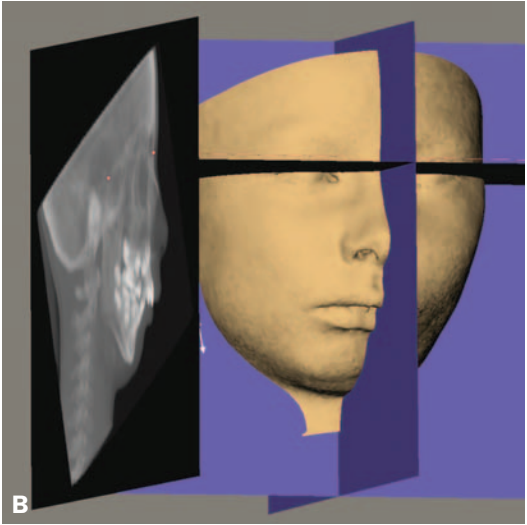


FIGURE 6-17 Multi-slice computed tomography scan of Patient B.R. Set-up of the three-dimensional anatomic Cartesian reference system centered in the sella. Note that both hard and soft tissues are linked to the same reference system (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>).

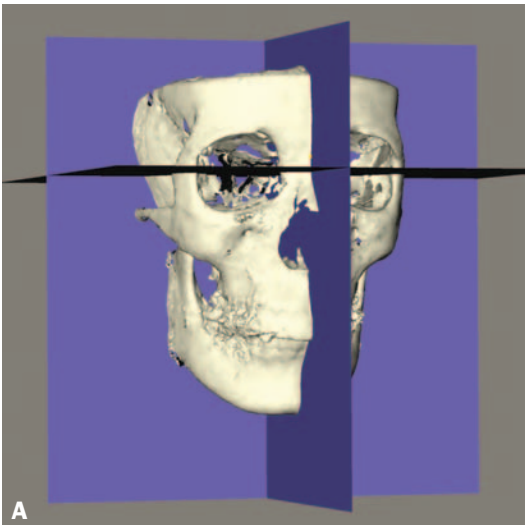


FIGURE 6-18 Set-up of the three-dimensional anatomic Cartesian reference system centered in the sella (step 6) (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>; CB MercuRay Cone-Beam Computed Tomography, Hitachi Medical Systems, Japan). Reproduced with permission from Dr. R. Kanomi, Kanomi Dental Clinic, Himeji, Japan.

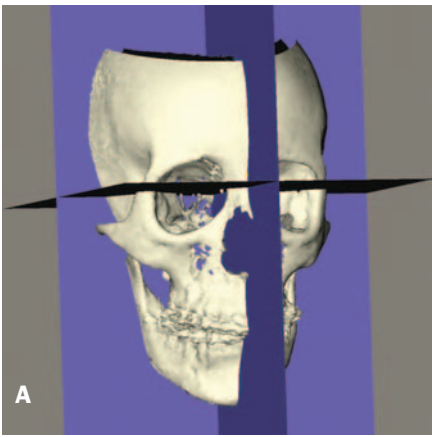
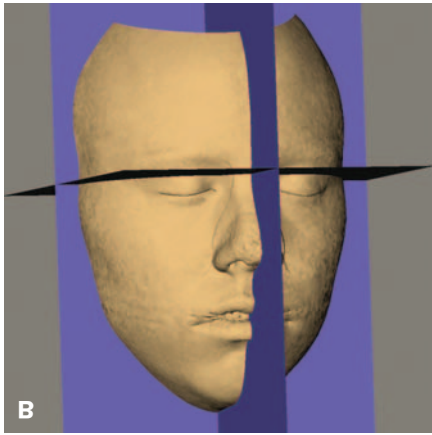


FIGURE 6-19 Set-up of the three-dimensional anatomic Cartesian reference system centered in the sella (step 6) (Maxilim, version 2.0, Medicim NV, Belgium; i-CAT Cone-Beam Computed Tomography, Imaging Sciences International, Inc, Hatfield, PA).



and soft tissue analysis (Figures 6-20 and 6-21; Tables 6-2 and 6-3).⁶⁵⁻⁶⁸ 3D cephalometry is a powerful measurement tool for diagnosis, treatment planning, and evaluation of treatment outcome of maxillofacial deformity. It represents a truly volumetric 3D presentation of hard and soft tissues of the patient's skull and allows in-depth analysis without superimposition of anatomic structures. 3D cephalometry allows real-size (1:1 scale) and real-time accurate and reliable 3D cephalometric analysis of hard and soft tissues. Moreover, accurate and reliable definition of bone-related soft tissue landmarks, proportions, and relationships between hard and soft tissue landmarks are possible, because of the in-depth analysis of the underlying bone. Because 3D cephalometry is based on a single data set, the development of bone-related soft tissue movement ratios is possible, in contrast to surface acquisition techniques. The setting up of a precise and reproducible anatomically meaningful 3D cephalometric reference system allows both cross-sectional and longitudinal comparison of 3D distances, and linear projective and orthogonal

Table 6-2 Selected Data of Three-dimensional Cephalometric Hard Tissue Measurements				
	Preoperative	Virtual planning	Postoperative (after distractor removal)	Long-term Postoperative (1 year after distractor removal)
Co _r -Go _r (mm)	39.8	49.2	49.3	46.3
Go _r -Pog (mm)	60.8	61.0	61.7	62.7
Co _r -Pog (mm)	83.6	91.1	92.3	94.2
Go _r -Go _l (mm)	79.9	79.8	81.6	79.8
N-Men (mm)	89.7	92.9	95.0	97.7
ANS-Men (mm)	43.4	46.6	48.0	50.7
S-PNS(mm)	31.2	31.8	34.9	34.7
S-Go _r (mm)	55.9	66.7	66.7	62.5
Gonial angle, (deg)	112.6	111.7	114.7	120.5
Facial midplane / z (deg)	10.3	6.1	7.7	6.6

Data for Patient B.R.

ANS-Men = anterior lower facial height; Co_r-Go_r = right mandibular vertical ramus length; Co_r-Pog = right total mandibular length; Facial midplane / z = frontal inclination of the facial midplane from the median z-plane; Go_r-Go_l = bicondylar width; Go_r-Pog = right mandibular horizontal ramus length; Gonial angle, = right gonial angle; N-Men = anterior total facial height; S-Go_r = right posterior total facial height; S-PNS = posterior midfacial height.

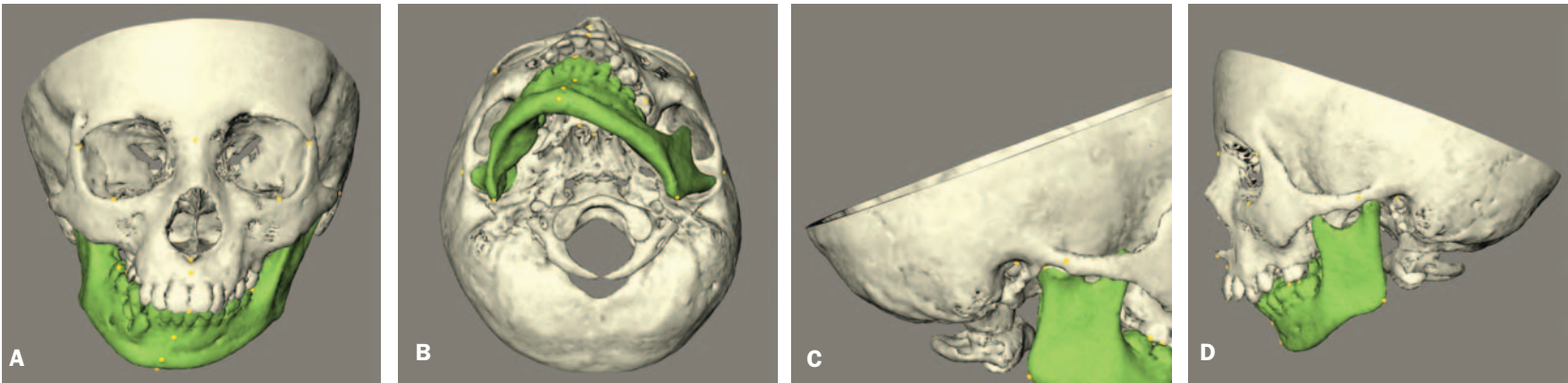


FIGURE 6-20 Multi-slice computed tomography scan of Patient B.R. Pretreatment three-dimensional (3D) computed tomography hard tissue surface representations with set-up of 3D cephalometric hard tissue landmarks (Maxilim, version 2.0, Medicim NV, Belgium). In Table 6-2, some 3D cephalometric hard tissue measurements are listed.

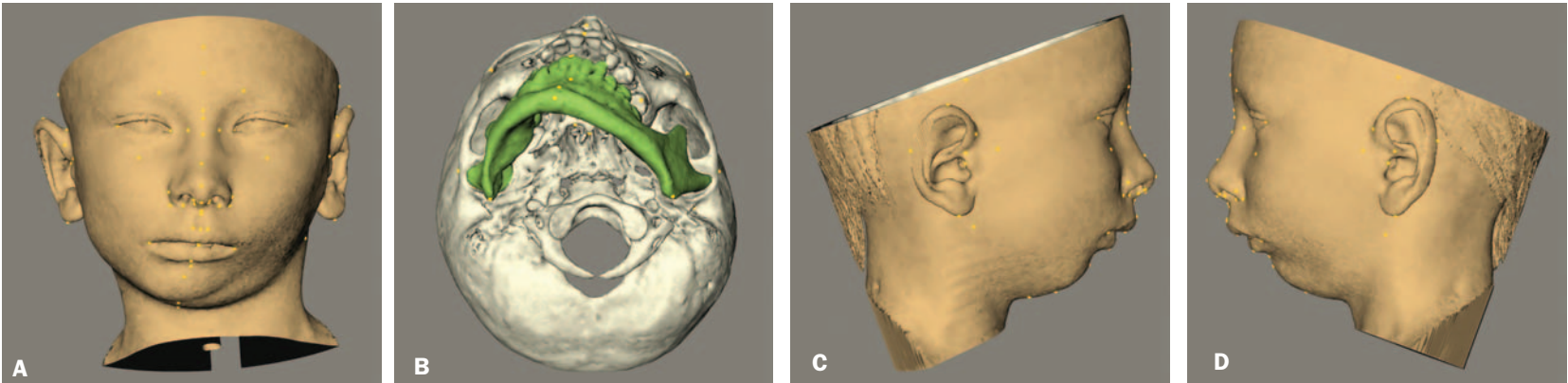


FIGURE 6-21 Multi-slice computed tomography scan of Patient B.R. Pretreatment three-dimensional (3D) computed tomography soft tissue surface representations with set-up of 3D soft tissue cephalometric landmarks (Maxilim, version 2.0, Medicim NV, Belgium). In Table 6-3 some 3D cephalometric soft tissue measurements are listed.

Table 6-3 Selected Data of Three-dimensional (3D) Cephalometric Soft Tissue Measurements

	Preoperative	3D Soft Tissue Simulation	Postoperative (after distractor removal)	Long-term Postoperative (1 year after distractor removal)
n-gn (mm)	47.2	51.4	49.8	53.4
sn-gn (mm)	96.6	101.0	100.4	104.5
t-gn (mm)	80.3	81.5	83.5	88.1
n-sn-pg (deg)	141.3	148.5	147.8	147.2
n-prn-pg (deg)	121.8	128.9	128.2	127.4
ch ₁ -ch ₁ /x (deg)	3.8	0.3	1.9	2.5

Data for Patient B.R.
ch₁-ch₁/x = inclination of the labial fissure from the horizontal x-plane; n-gn = morphologic height of the face; n-prn-pg = full soft tissue convexity angle; sn-gn = height of the lower face; n-sn-pg = soft tissue convexity angle; t-gn = right depth of the lower third of the face.

measurements. Moreover, analysis bias caused by improper use of measuring equipment or inadequate measuring method is decreased, because all measurements are fully automated. The major disadvantage of MSCT cephalometry remains the horizontal positioning of the patient during record taking that falsifies the position of the soft tissue facial mask due to gravity. Therefore, new CBCT scanners that allow vertical scanning of the patient in NHP are promising for the future.²⁴

Three-dimensional Model Analysis

Plaster dental models have long been the only truly three-dimensional record of the patient for diagnosis and treatment planning of maxillofacial deformity. Meanwhile, 3D image acquisition techniques allow the reproduction of 3D digital dental models, which are becoming increasingly popular and have the potential to provide more accurate and objective comparison of different treatment stages (eg, pretreatment model and virtual treatment goal). 3D dental models can be obtained by digitizing plaster dental models or dental impressions using CT or laser surface scanning. The 3D virtual scene approach allows virtual dynamic inspection of the 3D dental models separately, and provides different objective interactive measurement tools for objective analysis such as upper/lower arch width and length, tooth charts including the width of the individual teeth, and 3D distances, angles and proportions between measuring points (Figure 6-22). Moreover, by digitizing the wax bite using the same above-mentioned methods, the 3D virtual scene approach allows dynamic in-depth visualization and evaluation of the occlusion in the three planes, overbite and overjet measurements, and interactive definition of the ideal occlusion through translations and rotations in the three planes of space based on best-fit algorithms visualized by collision color maps (Figures 6-23 through 6-26). Another important cost-benefit factor is that 3D digital dental models are considerably space saving.

The 3D virtual approach has already led to innovating and exciting new orthodontic treatment strategies. These include 3D-based designs of passive-removable (eg, Invisalign; accessible at: <http://www.invisalign.com>), active indirectly bonded labial (eg, OrthoCAD; accessible at: <http://www.orthocad.com>), and fully customized lingual (eg, Incognito; accessible at: <http://www.lingualtechnik.de>) appliances, after a virtual set-up of the ideal occlusion using CAD/CAM engineering techniques.

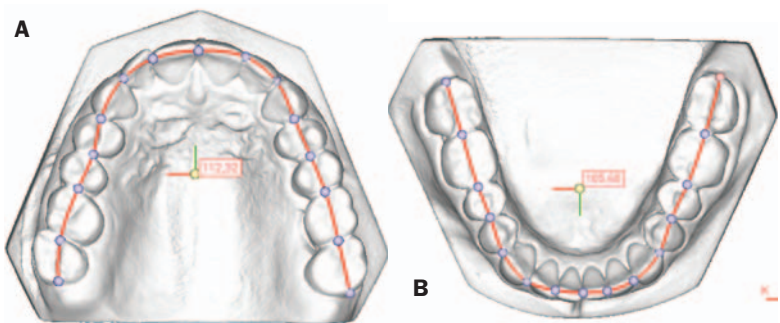


FIGURE 6-22 Virtual measurement of upper (A) and lower (B) arch length (DigiModel, version 2.2.1., OrthoProof Digital Models, The Netherlands).

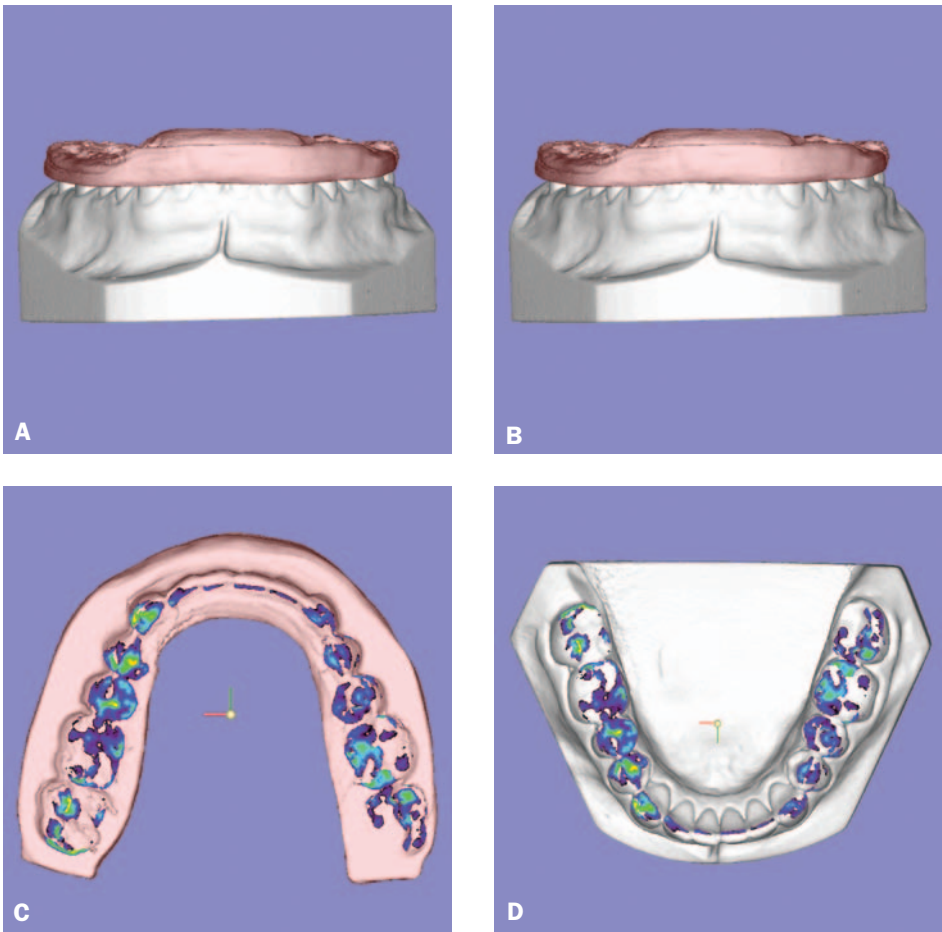


FIGURE 6-23 Bite alignment of the upper (A) and lower (B) digital dental models to wax bite can be performed manually or automatically, using best-fit visualized by collision color maps (C, D) (DigiModel, version 2.2.1., OrthoProof Digital Models, The Netherlands).

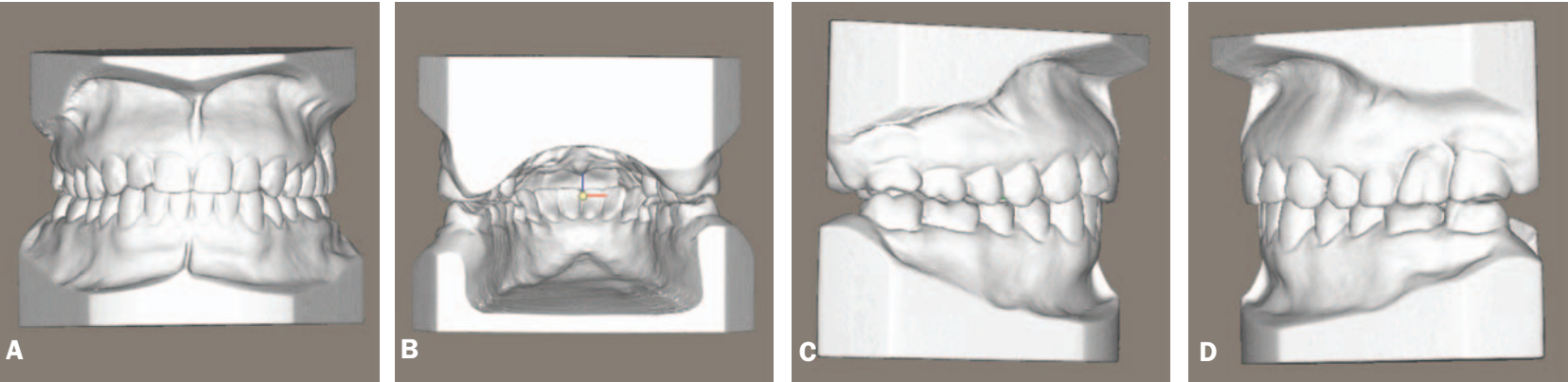


FIGURE 6-24 Virtual inspection of articulated three-dimensional digital dental models (DigiModel, version 2.2.1., OrthoProof Digital Models, The Netherlands).

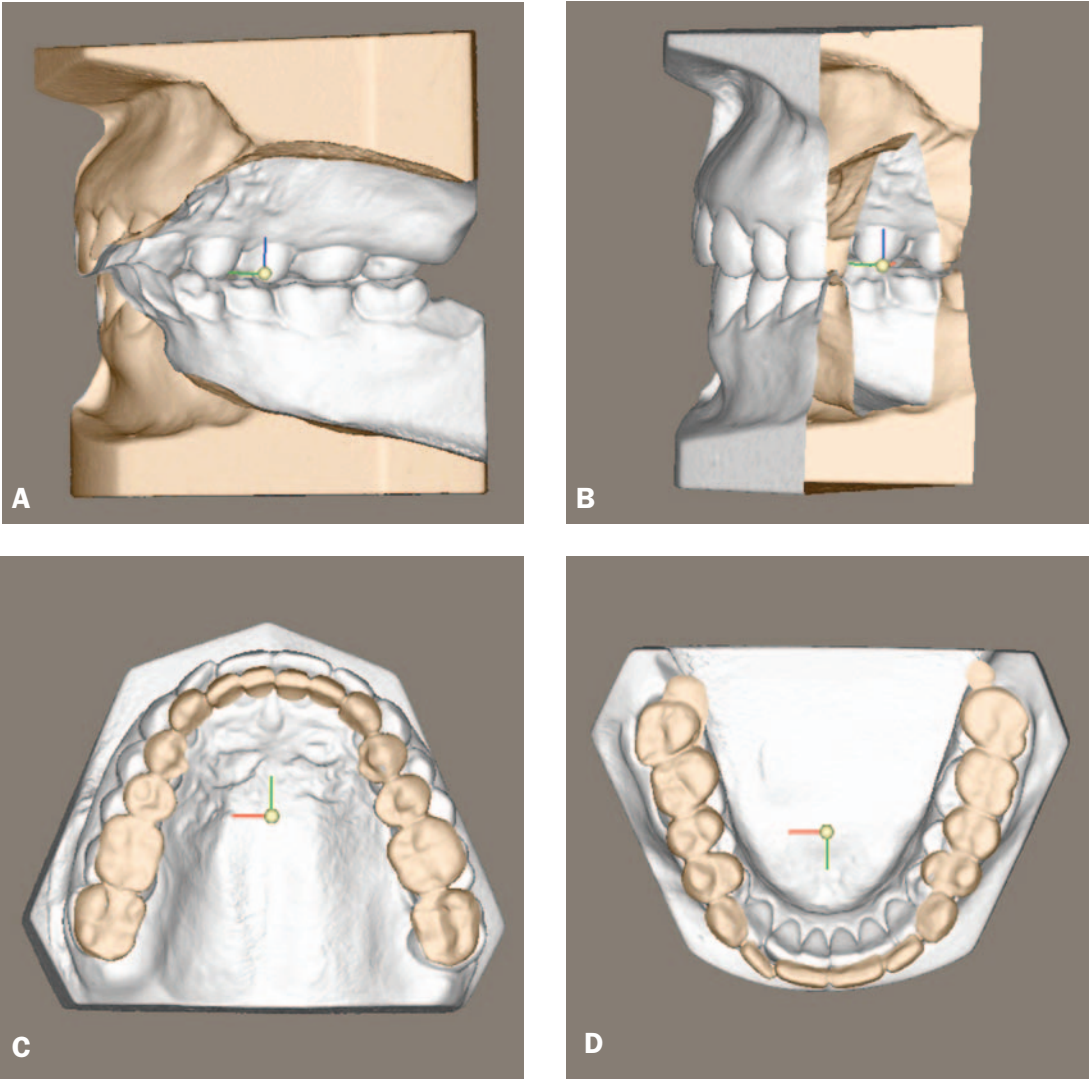


FIGURE 6-25 Virtual cuts through the articulated models. Sagittal virtual cut between the upper central incisors (A); transverse virtual cut between the second right premolar and first molar (B); occlusal virtual cuts at the level of the central part of the crowns of the lower (C) and upper (D) arches (DigiModel, version 2.2.1., OrthoProof Digital Models, The Netherlands).

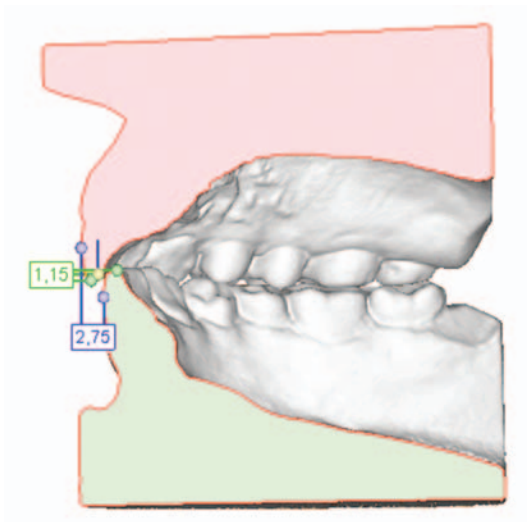


FIGURE 6-26 Virtual measurement of overbite and overjet (DigiModel, version 2.2.1., OrthoProof Digital Models, The Netherlands).

Three-dimensional Analysis of the Virtual Augmented Head Model

In the first section of this chapter, it was described how the CT data set of the patient can be augmented with a colored texture surface of the skin and detailed dental surface morphology. The virtual augmented model of the head recorded in its NHP position would be the ideal set-up for diagnosis and treatment planning of maxillofacial deformity (Figures 6-27 and 6-28). Standardization and registration of different volumetric and surface acquisition techniques is crucial. Moreover, the required imaging systems should be available for routine care of the patient with maxillofacial deformity.

Virtual Three-dimensional Treatment Planning

Three-dimensional Virtual Surgery

Currently, surface rendering is the most appropriate technique for 3D virtual surgery, which is ideally performed on the augmented skull model, if it is available. The 3D virtual approach allows both conventional model surgeries and maxillofacial osteotomies to be performed in the 3D virtual scene. Digital dental models can be rotated and translated in order to obtain an ideal occlusion. For the planning of orthognathic surgery and distraction osteogenesis, different tools have been developed to perform all types of maxillofacial osteotomies in the virtual scene with subsequent moving of bone fragments with interactive real-time cephalometric analysis (Figures 6-29 through 6-32).

Moreover, as far as distraction osteogenesis is concerned, different commercially available distraction devices have been implemented in real size (1:1) in different commercially available software packages. The 3D virtual scene approach allows for simulation of different types of osteotomies (eg, horizontal vertical ramus or gonial angle mandibular osteotomies, unilateral or bilateral), the positioning of different types of distraction devices (eg, unidirectional or multidirectional), and assessing three-dimensionally the effect of different distraction vectors; for example, potential interferences of the distraction arms of external mandibular multidirectional distraction devices to the skull during active distraction. Moreover, it is possible to evaluate the required size of internal distraction devices, as well as the relationship of the distraction device (screw holes or pins) to anatomic structures (eg, inferior alveolar nerve, tooth germs). Compared with the 3D virtual approach, stereolithographic models are less valuable for the planning of surgery, although they remain useful for the transfer of the virtual planning into the operation theatre (see subsection, “Transfer of 3D Planning to the Operation Theatre,” below).

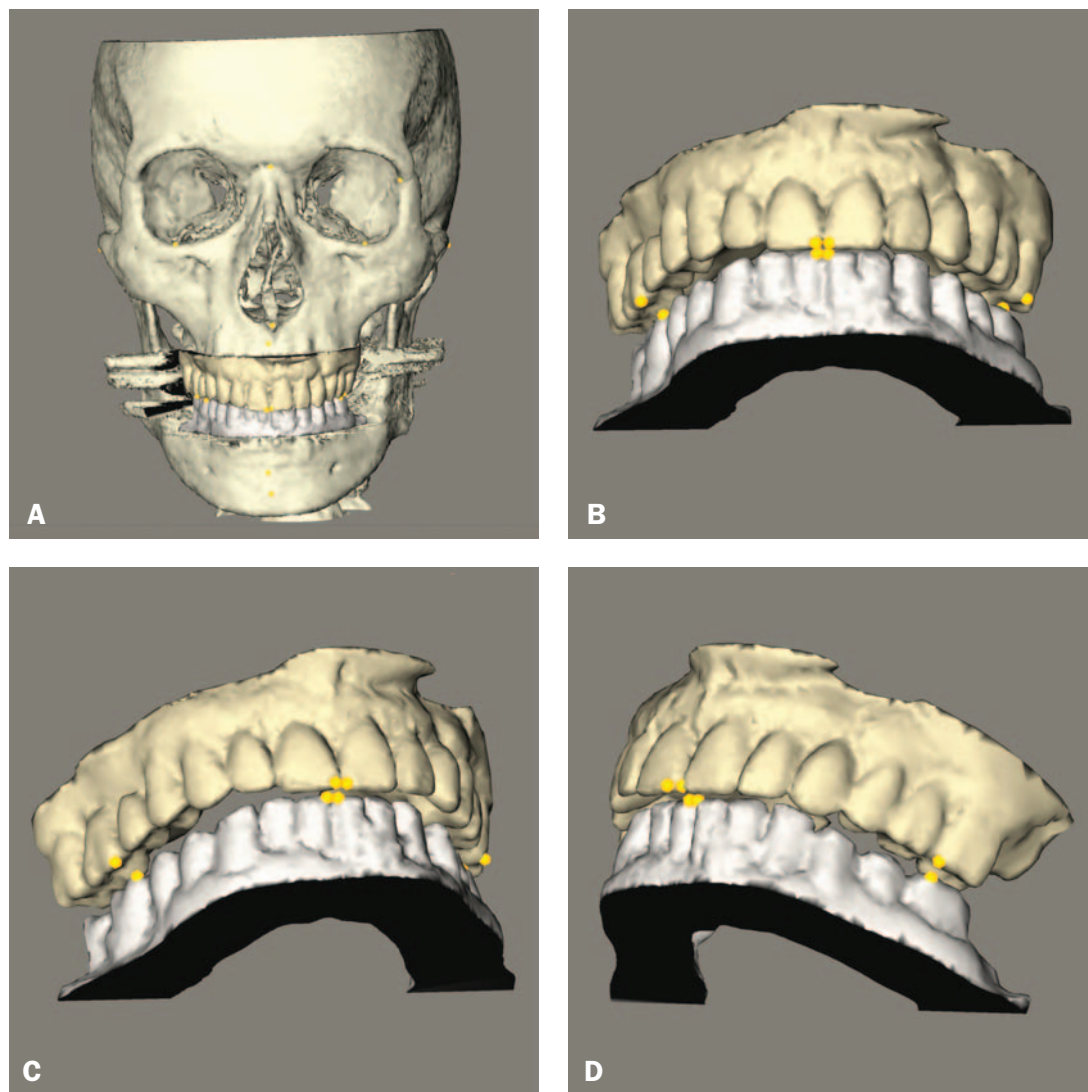


FIGURE 6-27 Augmenting the skull model with a detailed model of the dentition (Maxilim, version 2.0, Medicim NV, Belgium) allows more precise evaluation of the interocclusion relationship, and accurate and reliable three-dimensional definition of dental landmarks.

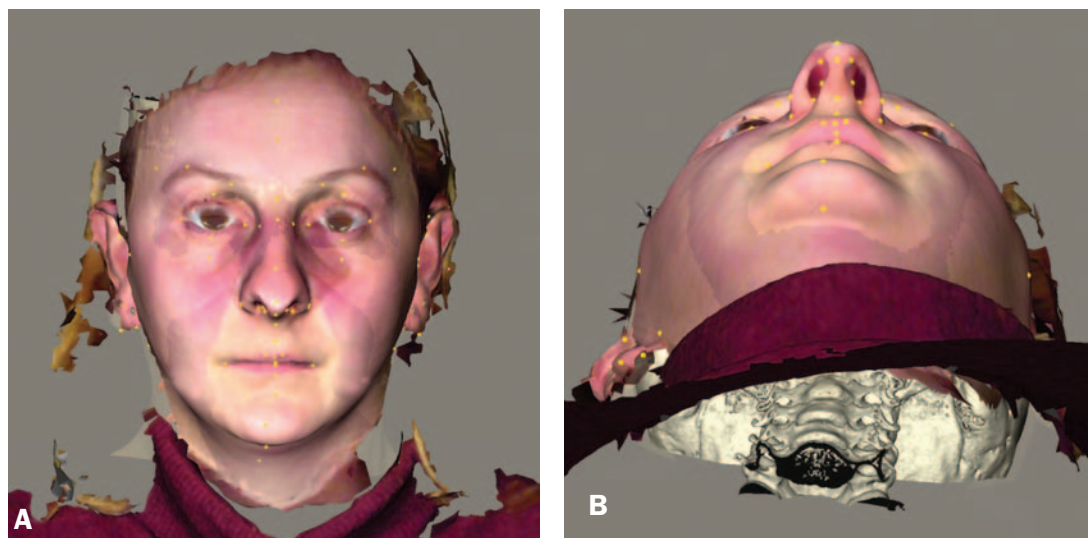


FIGURE 6-28 Multi-slice computed tomography scan of Patient F.L. Augmenting of the computed tomography (CT) hard and soft tissue surface representations of the patient with the natural complexion of the skin has the potential to allow more thorough three-dimensional cephalometric analysis. Registration (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>) of multi-slice CT scan with surface scan (3dMDface system, 3dMD, Atlanta, GA).

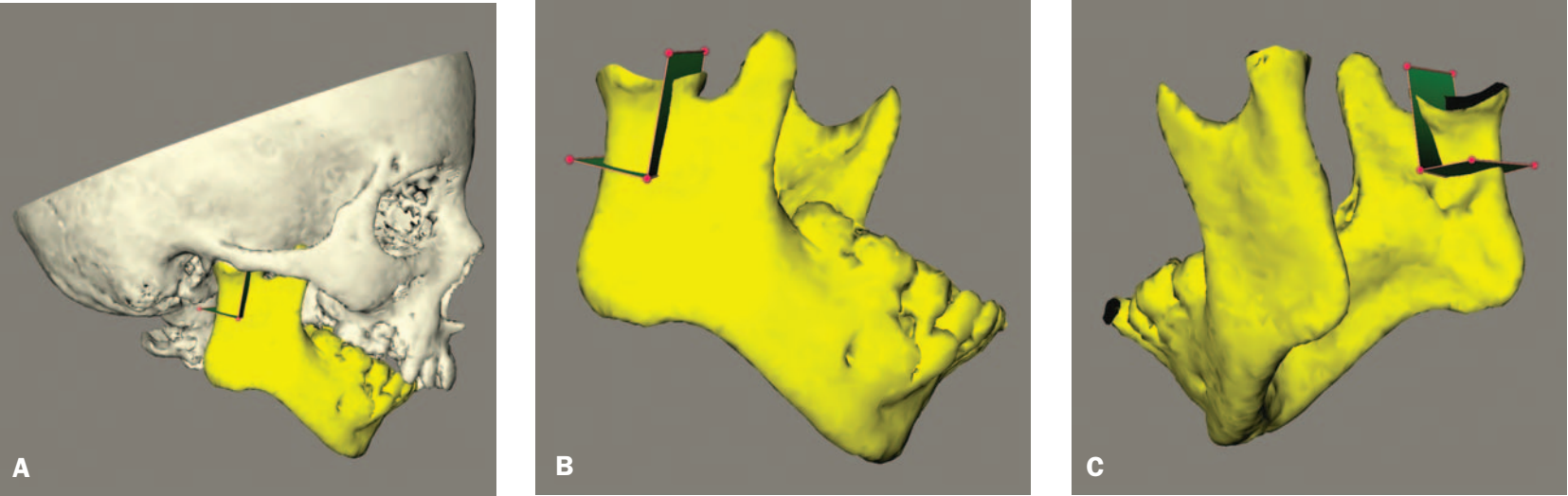


FIGURE 6-29 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Virtual planning of a reverse-L osteotomy of the right vertical mandibular ramus (Maxilim, version 2.0, Medicim NV, Belgium).

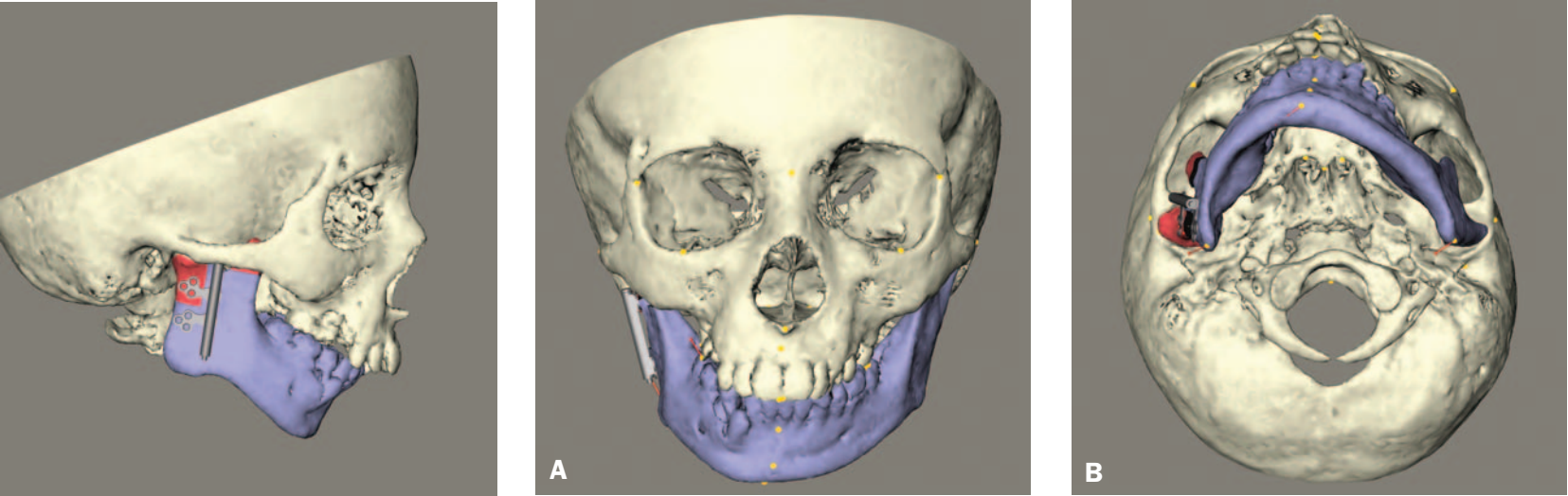


FIGURE 6-30 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Virtual planning of a reverse L-osteotomy of the right vertical mandibular ramus and positioning of an intraoral unidirectional Zürich Pediatric Ramus Distractor (cloverleaf design, KLS Martin, Tuttlingen, Germany; Maxilim, version 2.0, Medicim NV, Belgium).

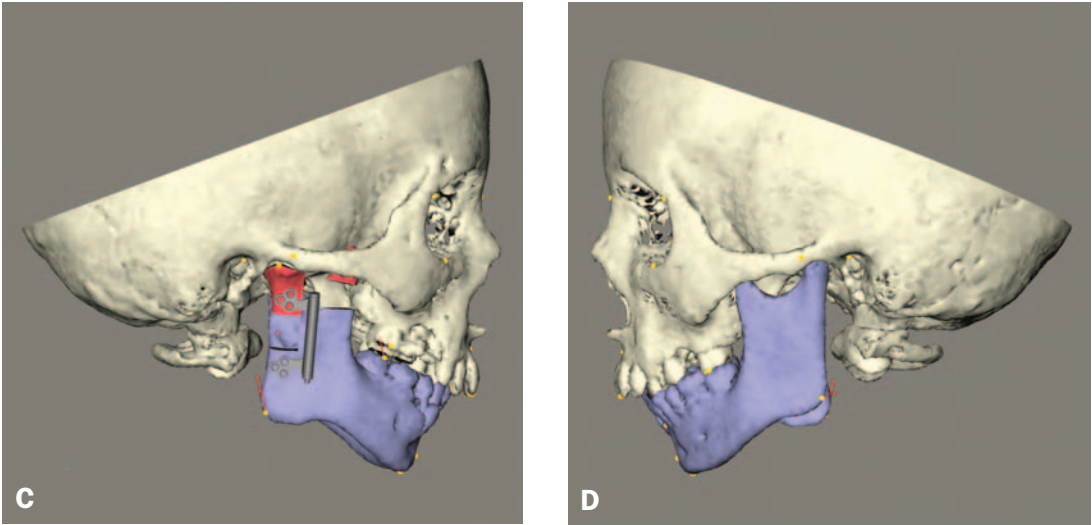


FIGURE 6-31 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. The virtual treatment goal is the reconstruction of the right condylar process with a 12 mm increase of right vertical mandibular ramus length after unidirection distraction osteogenesis (Maxilim, version 2.0, Medicim NV, Belgium). Note that the midline position of the chin is only partially corrected.

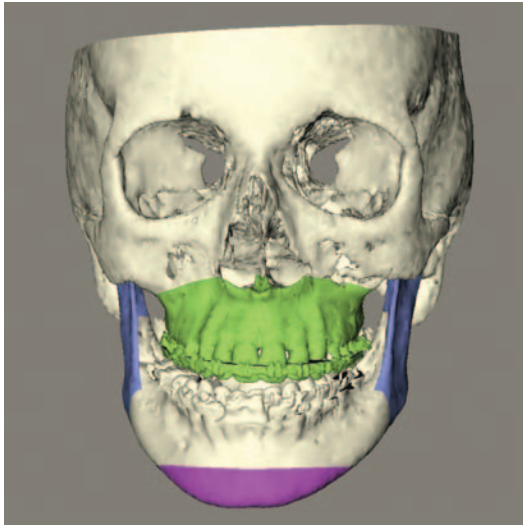


FIGURE 6-32 Multi-slice computed tomography, augmented skull model with a detailed model of the dentition for Patient B.R. Virtual Le Fort I osteotomy, bilateral sagittal split osteotomy (BSSO), and genioplasty (Maxilim, version 2.0, Medicim NV, Belgium).

Three-dimensional Soft Tissue Simulation

Three-dimensional soft tissue simulation after 3D virtual repositioning of the osteotomized bone segments is currently in development and validation (Figures 6-33 through 6-37). To compute the influence of surgery of the skeletal parts of the skull on the soft tissue facial mask, different mathematical algorithms that attempt to model the biomechanical behavior of the soft tissue envelope have been developed in research settings

by different research groups. With “mass-spring models,” the connections between the bone and skin surface are established with springs, and subsequently, a layered spring model of the soft tissues is set up.^{69,70} An alternative approach, based on “finite-element models” is the construction of the soft tissue volume as a tetrahedral mesh. The bone pushes the volumetric model, and the deformation of the soft tissues is automatically computed.^{55,63,71} A third approach uses a “mass-tensor model” in order to compute the soft tissue deformation, based on the interaction of the bone with a tetrahedral mesh of the facial soft tissues.^{72,73} The advantage of the mass-tensor model is that it is computationally cheap and allows very fast deformation computations, whereas finite-element models require more computational work and are slower. A disadvantage of the mass-spring model is that it does not reflect physical parameters in a straightforward way.

In order to provide a realistic 3D soft tissue simulation, a correct acquisition of the data for the augmented head model is extremely important. During CT acquisition, the patient has to be in a relaxed status, ideally in NHP. For example, straining of the lips in patients with lip incompetence will cause bad 3D soft tissue simulations. As already pointed out, new CBCT scanners now allow vertical scanning of the patient in NHP and will allow more realistic 3D soft tissue simulations. Moreover, the combination of mathematical algorithms with 3D cephalometric

data of clinical bone-related soft tissue movement will probably be the keystone to accurate and reliable 3D soft tissue simulation.

In a time of evidence-based medicine, it is important that 3D soft tissue simulation is validated. Therefore, large-scale clinical prospective studies are needed. In the design of such studies, it is important that postoperative CT scanning be performed 3 or 4 months after surgery, once all swelling has disappeared, in order to allow unbiased comparison of the virtual 3D soft tissue simulation with the actual treatment outcome. Up to now, and to the best of our knowledge, no extensive evidence-based data on this subject have yet been published in the literature. These results are, however, expected in the near future. Once validated, the transition toward commercial software for clinical routine will be justified.

Transfer of 3D Planning to the Operation Theatre

After 3D virtual surgery and 3D soft tissue simulation have been planned, the virtual planning has to be precisely transferred into the operation theatre. The transfer of 3D virtual planning of osteotomies, repositioning of the osteotomized bone segments, and/or positioning of distraction devices on the patient are still in their early phases, and much needs to be developed. The use of commercial callipers, virtual templates, stereolithographic models, CAD/CAM techniques, and CAS have been reported in the literature

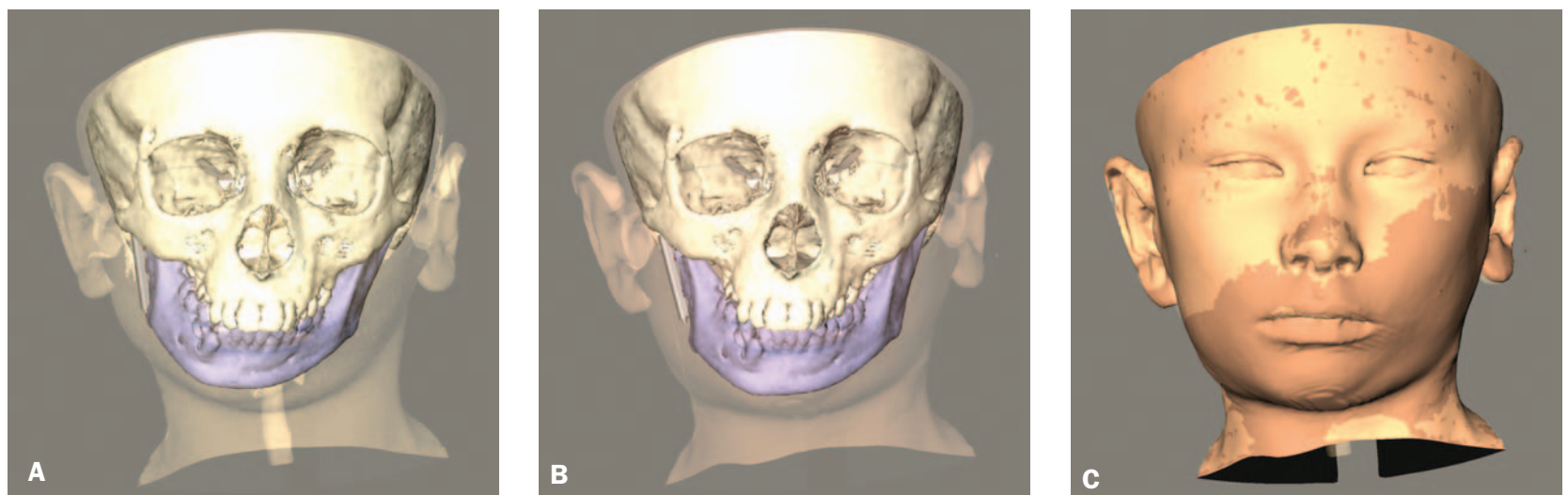


FIGURE 6-33 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Three-dimensional soft tissue simulation (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>) after virtual planning of a 12 mm increase of the right vertical mandibular ramus by unidirectional distraction osteogenesis with the intraoral Zürich Pediatric Ramus Distractor (KLS Martin, Tuttlingen, Germany). Frontal view before (A) and after (B, C) virtual DO.

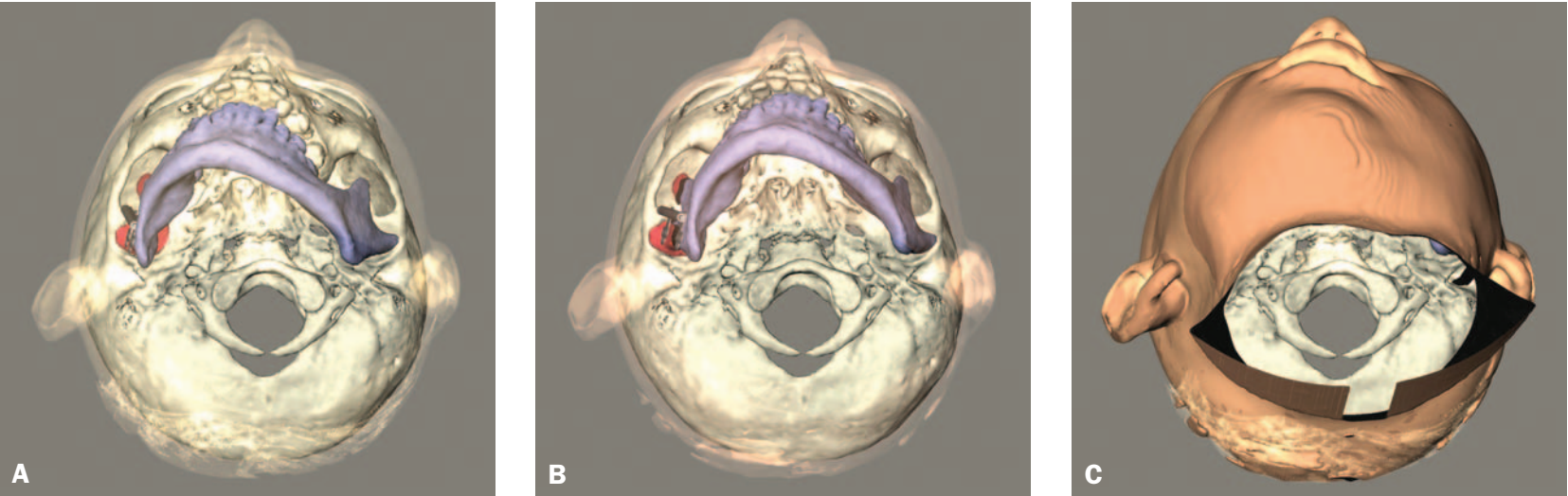


FIGURE 6-34 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Three-dimensional soft tissue simulation (Maxilim, version 2.0, Medicim NV, Belgium) after virtual planning of a 12 mm increase of the right vertical mandibular ramus by unidirectional distraction osteogenesis with the intraoral Zürich Pediatric Ramus Distractor (KLS Martin, Tuttlingen, Germany). Base view before (A) and after (B, C) virtual DO.

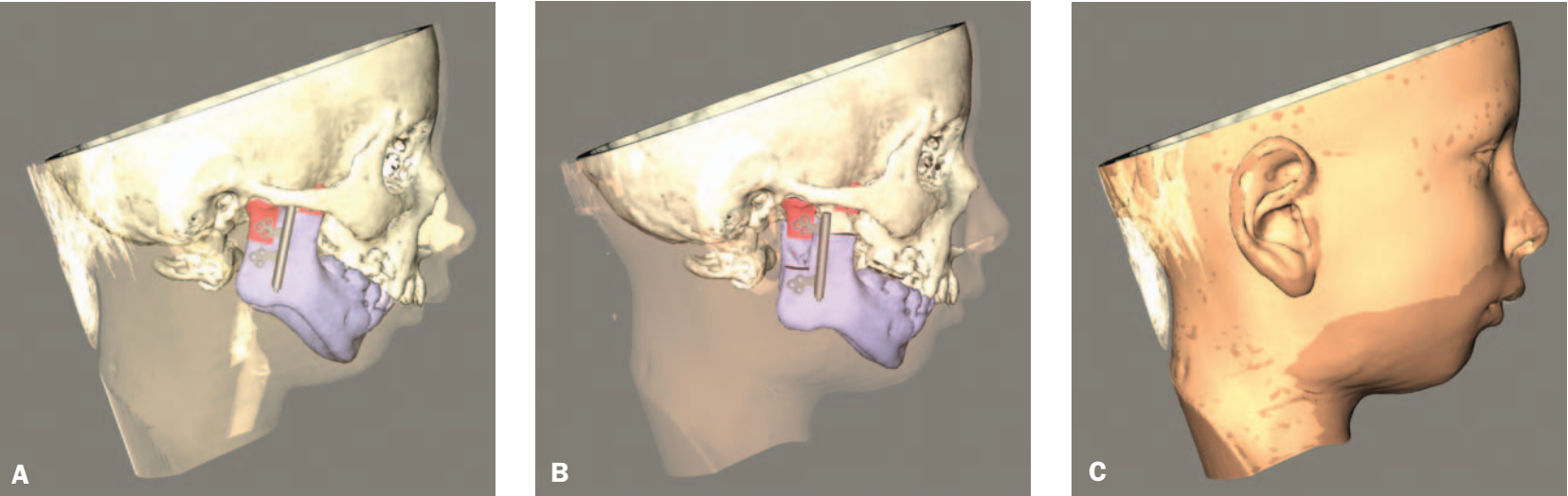


FIGURE 6-35 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Three-dimensional soft tissue simulation (Maxilim, version 2.0, Medicim NV, Belgium) after virtual planning of a 12 mm increase of the right vertical mandibular ramus by unidirectional distraction osteogenesis with the intraoral Zürich Pediatric Ramus Distractor (KLS Martin, Tuttlingen, Germany). Profile view right before (A) and after (B, C) virtual DO.

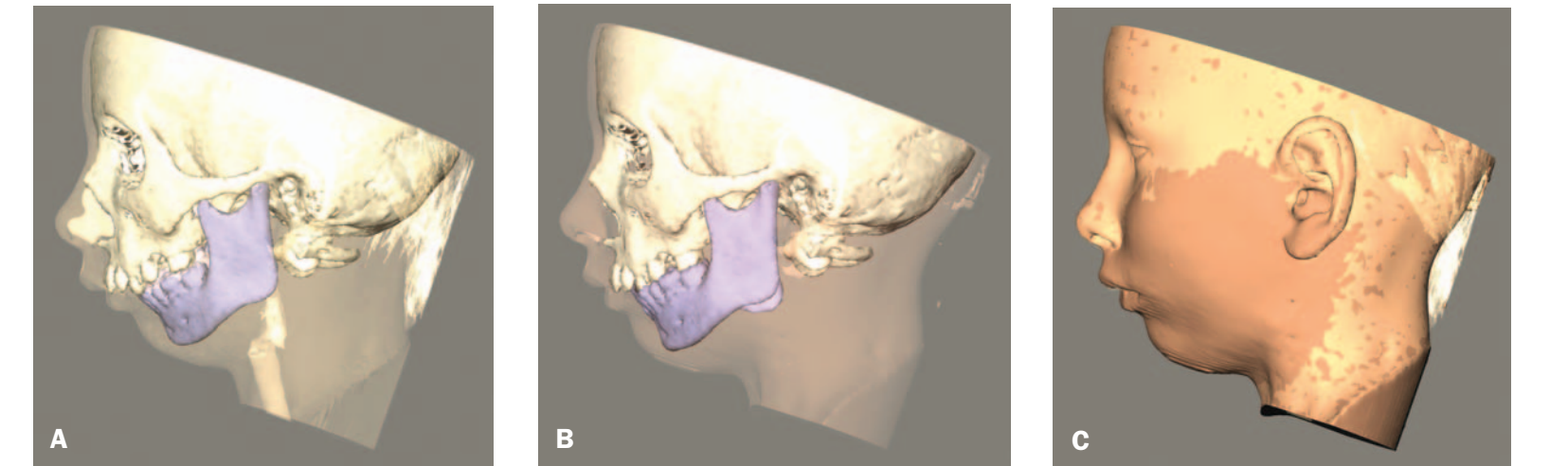


FIGURE 6-36 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Three-dimensional soft tissue simulation (Maxilim, version 2.0, Medicim NV, Belgium) after virtual planning of a 12 mm increase of the right vertical mandibular ramus by unidirectional distraction osteogenesis with the intraoral Zürich Pediatric Ramus Distractor (KLS Martin, Tuttlingen, Germany). Profile view left before (A) and after (B, C) virtual DO.

(see Figure 6-37A, and Figures 6-38 through 6-41).^{52,53,61,62,68,74}

Three-dimensional Evaluation of Treatment Outcome

In a time of evidence-based medicine, objective evaluation of treatment outcome is essential to improve the care of patients with maxillofacial deformity. Although combined orthodontic treatment and orthognathic surgery is a routine procedure for the patient with maxillofacial deformity, some problems still remain unresolved (eg, condylar resorption). Distraction osteogenesis has become a mainstay in the treatment of patients with congenital maxillofacial deformity, although clinical evidence-based data are lacking⁷⁵; for example, there is no evidence that osteodistraction produces better results and has lower morbidity than conventional growth center transplantation and separate soft tissue augmentation.⁷⁶ Prospective randomized multicenter control trials, such as the Eurocran Distraction Study, are therefore crucial in order to collect evidence-based data.⁷⁷

Rapid advances in the field of 3D imaging will hopefully not only bring with them new insights and concepts, but also allow collecting of evidence-based data in order to improve care of the patient with maxillofacial deformity. The “3D virtual visualization paradigm” allows not only for comparison of the pretreatment status and the treatment outcome, but also the 3D virtual treatment goal with the actual treatment outcome, in an unprecedented way. Two techniques, each having its proper advantages and disadvantages, can be used: (1) rigid registration and (2) the superimposition on a 3D cephalometric reference system.

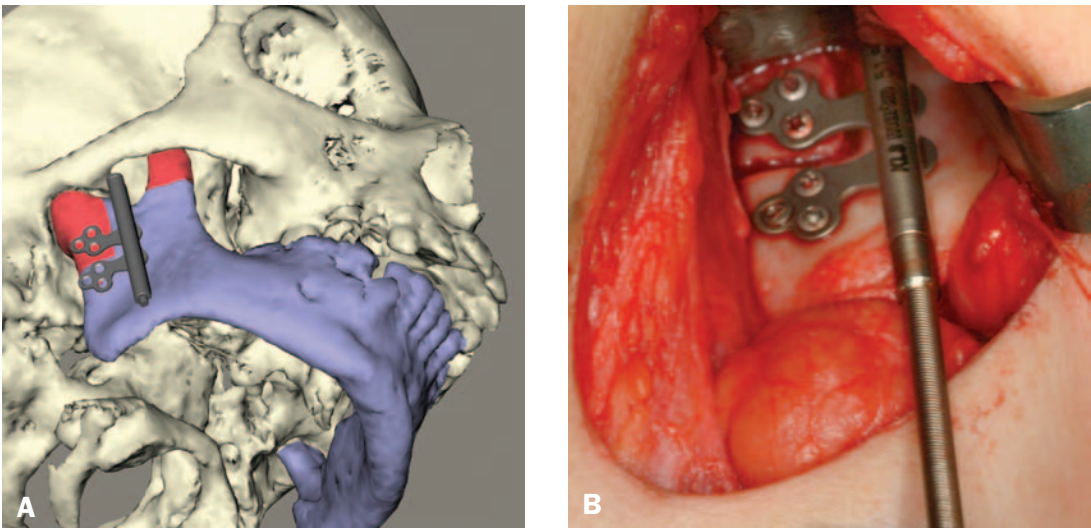


FIGURE 6-37 Multi-slice computed tomography scan of Patient B.R. Same patient as Figure 6-9. The virtual planning (A) (Maxilim, version 2.0, Medicim NV, Belgium) of a right reverse-L osteotomy, position, and vector of an internal unidirectional Zürich Pediatric Ramus Distractor (cloverleaf design, KLS Martin, Tuttlingen, Germany) is transferred to the operation theatre using a commercial calliper (10 mm anterior and parallel to the posterior border of the vertical mandibular ramus and 15 mm inferior to the mandibular incisura). Intraoperative view (B) after a right submandibular approach.

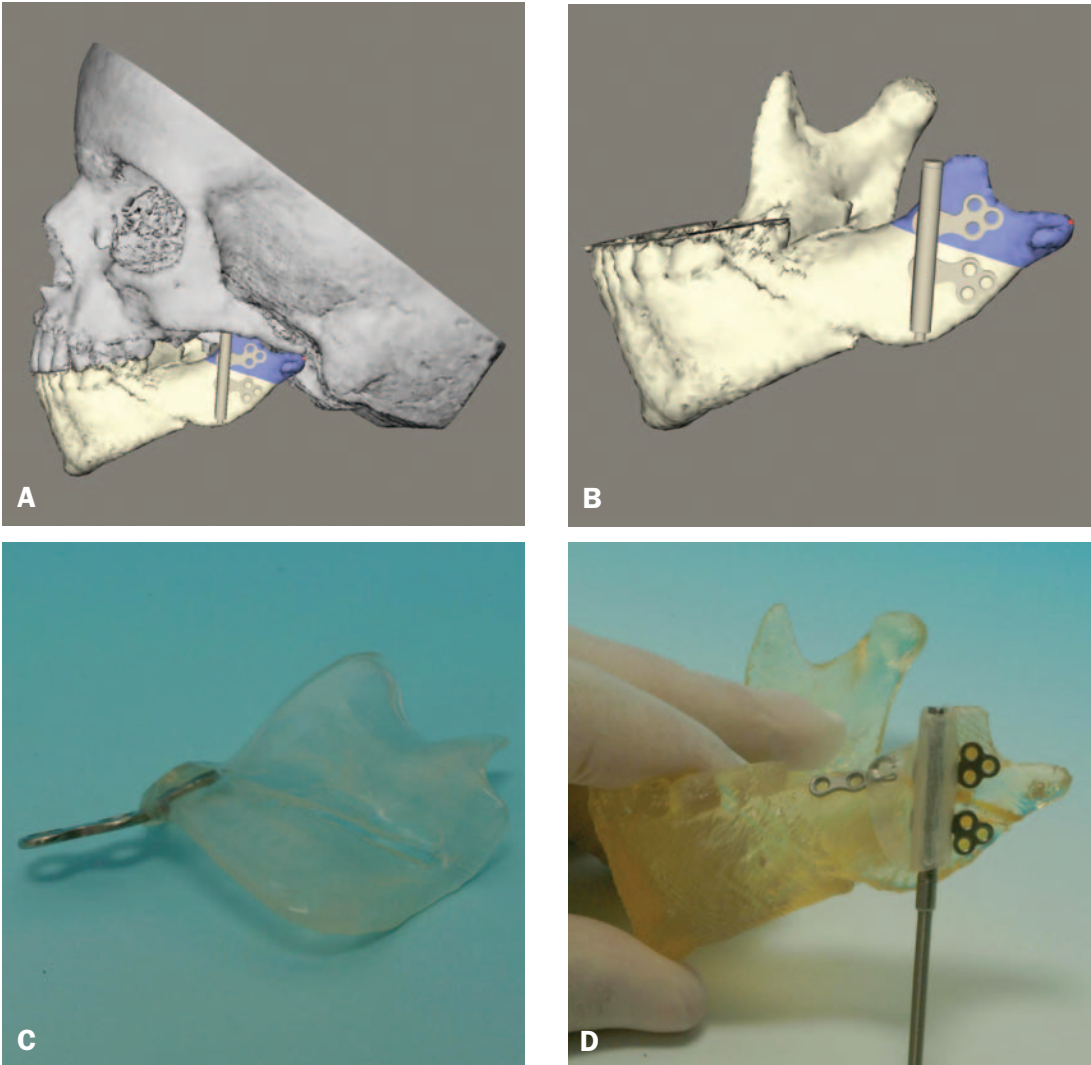


FIGURE 6-38 Multi-slice computed tomography scan of Patient H.T. Transfer of virtual DO planning in a 5-year-old male patient with left hemifacial microsomia using a stereolithographic (STL) model of the mandible (Maxilim, version 2.0, Medicim NV, Belgium). The virtual horizontal osteotomy of the left vertical mandibular ramus and positioning of an intraoral unidirectional Zürich Pediatric Ramus Distractor (cloverleaf design, KLS Martin, Tuttlingen, Germany) are transferred to the operation theatre using an STL model of the isolated mandible and custom-made surgical guides. Note that the virtual planned osteotomy line and screw holes of the intraoral distraction device are color marked in the STL model. Custom-made acrylic surgical guides are fabricated to transfer the osteotomy line and the positioning and inclination of the internal distraction device.

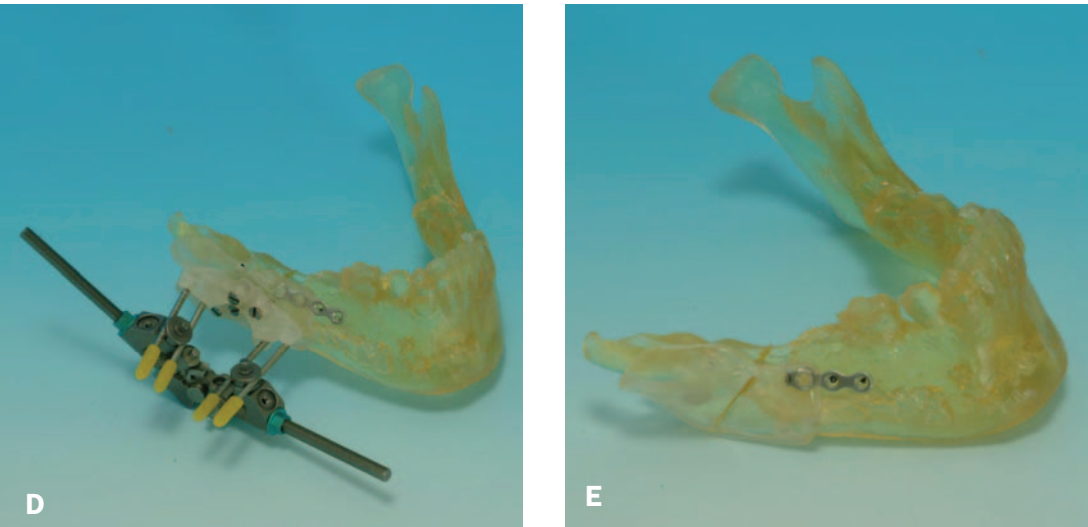
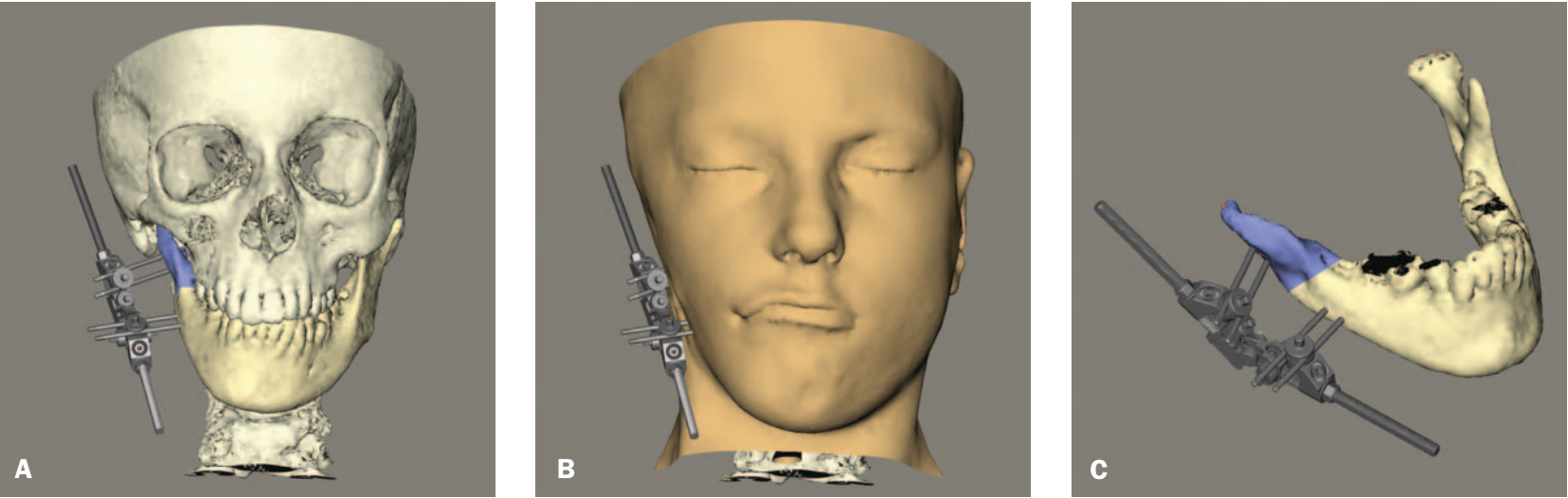


FIGURE 6-39 Multi-slice computed tomography scan of Patient S.J. Transfer of virtual DO planning in a 10-year-old female patient with right hemifacial microsomia using a stereolithographic (STL) model of the mandible (Maxilim, version 2.0, Medicim NV, Belgium). The unilateral osteotomy at the right gonial angle and positioning and vector of an external multidirectional 3DX Distractor (KLS Martin, Tuttlingen, Germany) are transferred to the operation theatre using an STL model of the isolated mandible and custom-made surgical guides. Note that the virtual planned osteotomy line and pinholes of the external distraction device are color marked in the STL model. Custom-made acrylic surgical guides are fabricated to transfer the osteotomy line and the positioning of the distraction device. Note that the custom-made guide is still very bulky.

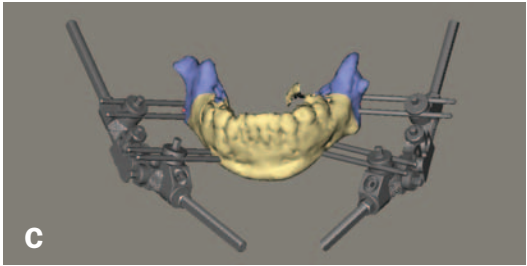
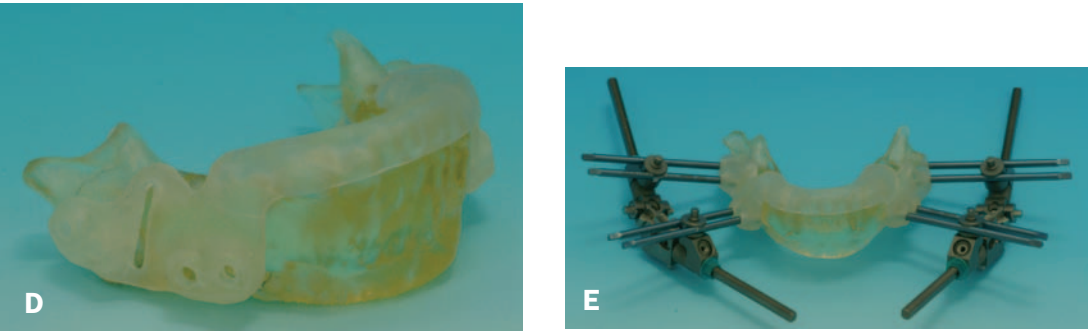
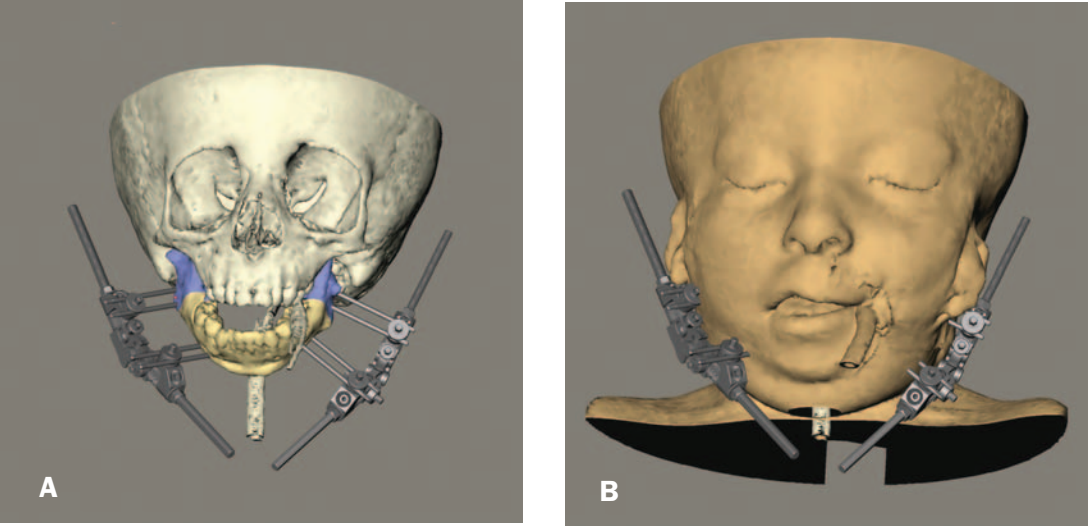


FIGURE 6-40 Multi-slice computed tomography scan of Patient H.J. Transfer of virtual DO planning in a 2-year-old female patient with Treacher Collins syndrome and obstructive sleep apnea syndrome. Bilateral osteotomies at the gonial angles and positioning of bilateral virtual external multidirectional 3DX Distractors (KLS Martin, Tuttlingen, Germany) are transferred to the operation theatre using a stereolithographic (STL) model of the isolated mandible and custom-made surgical guides. The virtual planned osteotomy lines and pinholes of the distraction pins of both external distraction devices are color marked in the STL model. Custom-made acrylic surgical guides are fabricated to transfer the osteotomy lines, positioning, and inclination of the distraction pins of both external devices.

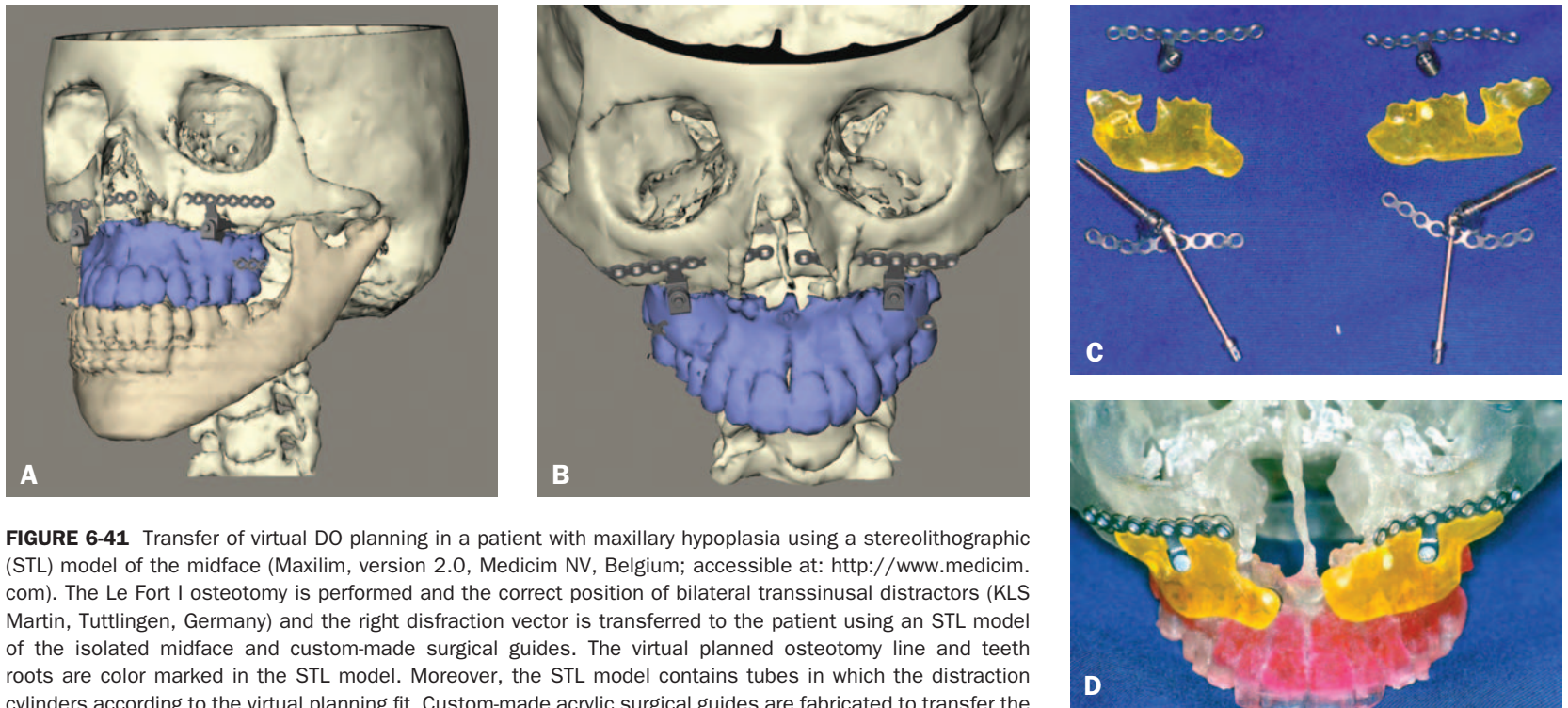


FIGURE 6-41 Transfer of virtual DO planning in a patient with maxillary hypoplasia using a stereolithographic (STL) model of the midface (Maxilim, version 2.0, Medicim NV, Belgium; accessible at: <http://www.medicim.com>). The Le Fort I osteotomy is performed and the correct position of bilateral transnasal distractors (KLS Martin, Tuttlingen, Germany) and the right distraction vector is transferred to the patient using an STL model of the isolated midface and custom-made surgical guides. The virtual planned osteotomy line and teeth roots are color marked in the STL model. Moreover, the STL model contains tubes in which the distraction cylinders according to the virtual planning fit. Custom-made acrylic surgical guides are fabricated to transfer the positioning and inclination of the distraction device. Reproduced with permission from N. Nadjmi, Eeuwfeestkliniek, Antwerp, Belgium.

Rigid Registration

Registration techniques are based on similarity measures between two (eg, pre- and posttreatment) or more (eg, pretreatment, treatment goal, and posttreatment) data sets. With rigid registration, a rotation and translation is searched, which aligns the data sets and thus increases the similarity of two or more data sets. Different types of rigid registration exist: point-based, surface-based, and voxel-based rigid registrations. Point-based rigid registration only uses corresponding points to compute the rotation and translation between data sets. The residual distance between the points will pair after registration is minimized. Surface-based rigid registration uses surface information of two data sets to compute the rotation and translation between data sets. Corresponding points and shapes are searched and the distance after rotation and translation is minimized. Voxel-based rigid registration uses the gray-value information of two data sets to compute the rotation and translation between data sets, by maximizing the mutual information between both data sets.

With point-based registration, validation of the posttreatment outcome is only possible if one can find corresponding points that have not moved during orthodontics or surgery. From a technical point of view, superimposition of data sets based on a reference frame is a smart application of point-based matching. Reference frames are set up based on anatomic points, and the

translation and rotation between the reference frames are computed in order to allow them to coincide. Based on some indicated points, the data sets are superimposed. With this type of registration, it is crucial that the points that define the reference frame are indicated with the highest precision, because it heavily influences the results of the superimposition. Superimposition on a 3D cephalometric reference system (Swennen 2005, Swennen 2006), is actually a form of point-based registration.

To evaluate treatment outcome with surface-based registration, parts of the skull or facial soft tissues that remained stable during treatment are necessary. 3D CT hard or soft tissue surface representations that did not undergo any changes during the correction of the dentofacial deformity can be used. As far as surface acquisitions systems are concerned, the forehead (eg, 3D photograph or laser surface scanning) has been used for surface-based registration. Superimposition based on rigid registration has been used to assess volumetric facial changes following orthognathic surgery using surface-based rigid registration. Unfortunately, since the forehead is an almost flat surface without a lot of curvature information, it is likely that the surface registration methods will have a low performance.

Voxel-based registration is a more preferred registration method (Figures 6-42 through 6-44). Based on a subvolume that has not changed during treatment, very accurate matching is

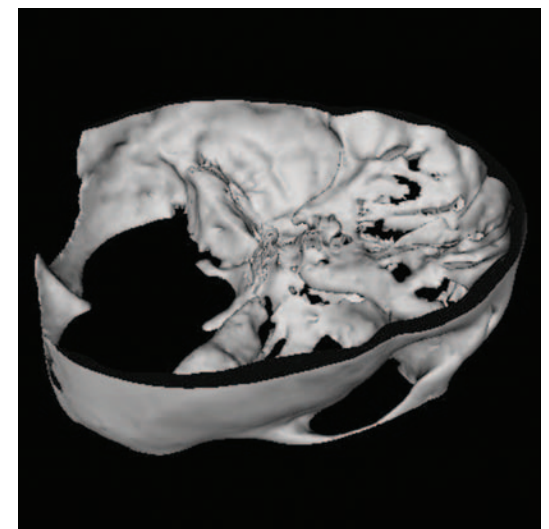


FIGURE 6-42 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Subvolume of the skull obtained by maximization of mutual information for voxel-based registration of the postoperative (1 week after distractor removal) toward the preoperative hard and soft tissue image volume (Maxilim, version 2.0, Medicim NV, Belgium).

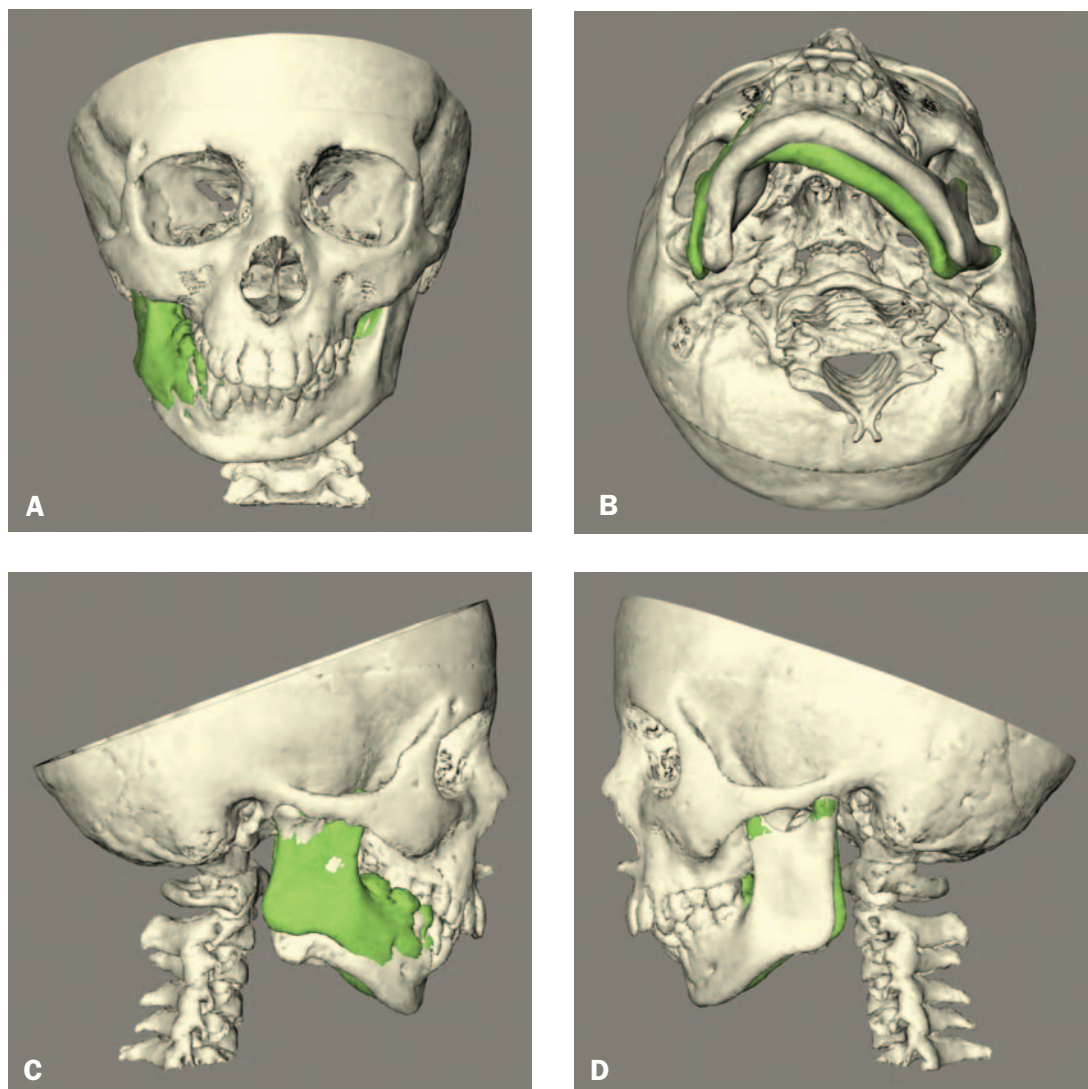


FIGURE 6-43 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Voxel-based rigid registration of the postoperative (1 week after distractor removal) toward the preoperative hard tissue image volume. Voxel-based registration was computed using maximization of mutual information (see Figure 6-42.) (Maxilim, version 2.0, Medicim NV, Belgium).

possible (see Figure 6-42). Very often, the region at the level of the skull base, or the orbits, has not changed. All image information within this subvolume is then used to automatically register the volumes after a rough initialization. The main disadvantage of voxel-based rigid registration remains its limits both in application during growth and for cross-sectional evaluation of treatment outcome. To use voxel-based registration during growth, it is necessary to know which subvolume of the skull is likely to be the most stable during growth. For cross-sectional evaluation, it is necessary to know which subvolume of the human skull is the most unchanged, and age-, sex-, and race-related. Based on the current knowledge of craniofacial morphology and growth, these subvolumes have to be searched in the area of the skull base. Up to now, however, no evidence-based data have been published on which subvolumes of the skull base will be the most suitable for this purpose.

To visualize the differences between registered surfaces, color coding can be used. Profitt and Cevdanes used cranial base superimposition with a color-coded method to display condylar

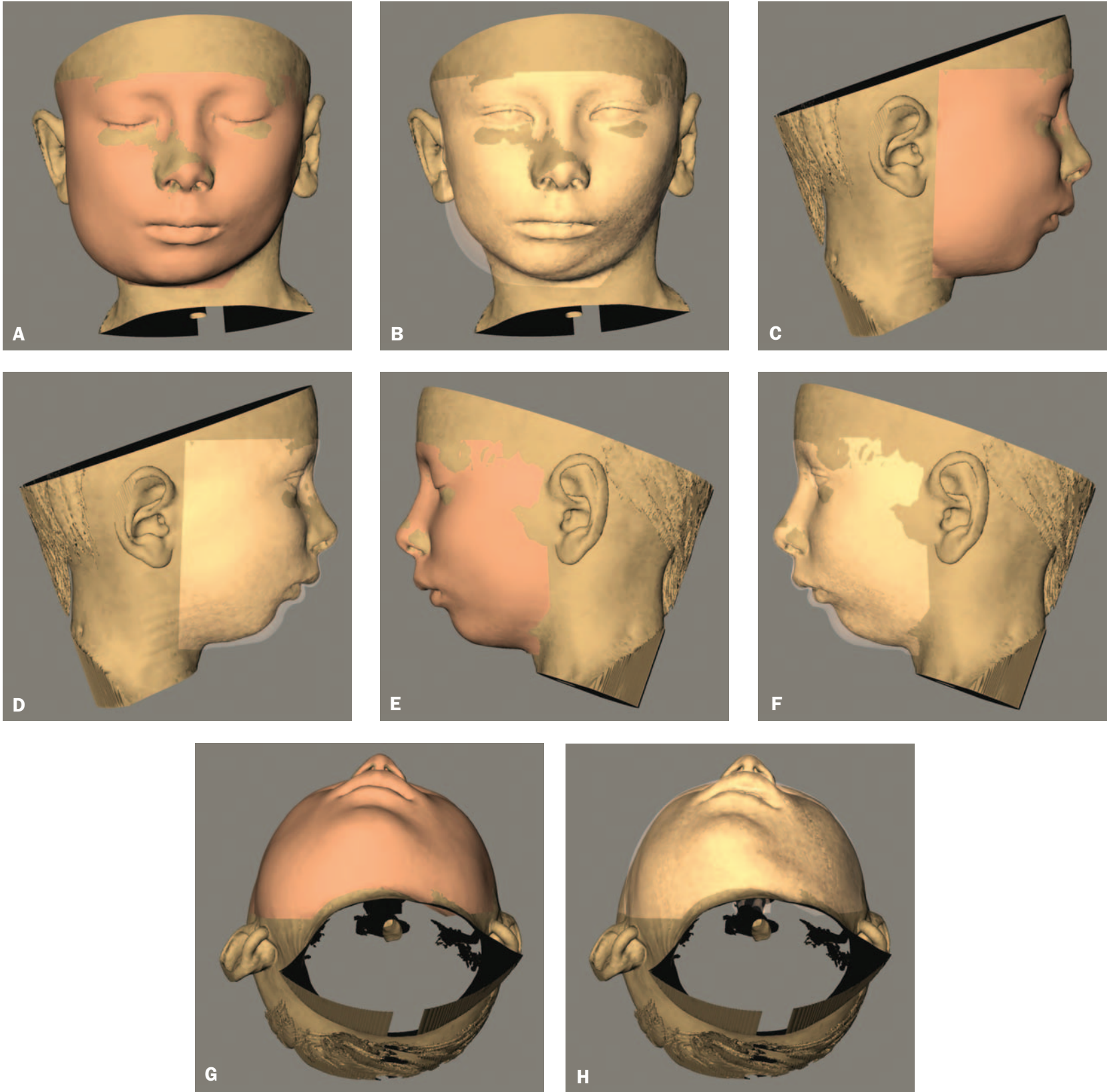


FIGURE 6-44 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Voxel-based rigid registration of the postoperative (1 week after distractor removal) toward the preoperative soft tissue image volume. Voxel-based registration was computed using maximization of mutual information based on the skull base subvolume (see Figure 6-42.) (Maxilim, version 2.0, Medicim NV, Belgium). Note that there is still significant swelling.

changes and remodeling after orthognathic surgery, and expect that this method can be used as a predictor for long-term condylar change and adaptation.⁷⁸

Superimposition on the 3D Cephalometric Reference System

Superimposition on the 3D cephalometric reference system is an alternative method to surface- and voxel-based rigid registrations, to evaluate treatment outcome of maxillofacial deformity (Figures 6-45 and 6-46).^{5,42} Compared with the

latter registration systems, it has the advantage that it can be used for cross-sectional evaluation of craniofacial morphology and longitudinal evaluation during craniofacial growth. Moreover, superimposition on the 3D cephalometric reference system has the advantage that the treatment outcome on both hard and soft tissues can be compared when linked to the same Cartesian anatomic coordinate system. Because superimposition on the 3D cephalometric reference system is basically a form of point-based rigid registration, the result of the registration depends on the stability, precision, and reliability of the points.

It has been shown that the set-up of the 3D cephalometric reference system is highly precise and reliable.⁴² It is, however, important to take into account the fact that the sella and nasion are relatively fixed landmarks and can change during growth.⁷⁹ Since rigid surface- and voxel-based rigid registrations are currently not valuable for long-term evaluation during craniofacial growth, superimposition on the 3D cephalometric reference system presents a valuable tool, especially toward the treatment outcome of distraction osteogenesis during growth.

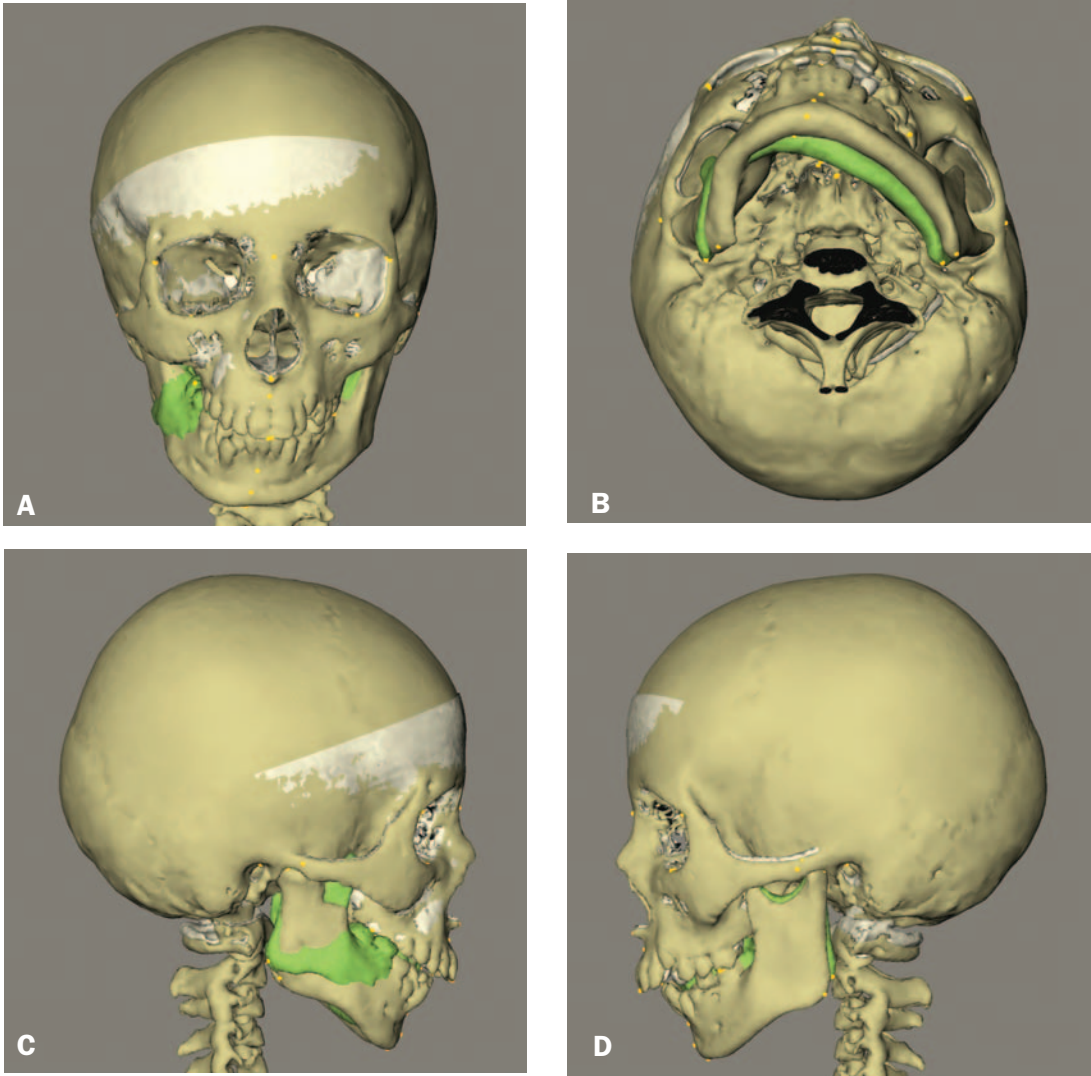


FIGURE 6-45 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Superimposition on the three-dimensional cephalometric reference system of the preoperative and postoperative long-term (1 year after distractor removal) hard tissue surface representations (Maxilim, version 2.0, Medicim NV, Belgium). Note the anteroinferior displacement of the nasomaxillary complex, the lateral development of the midfacial complex with lateroinferior relocation of the zygomatic arch.

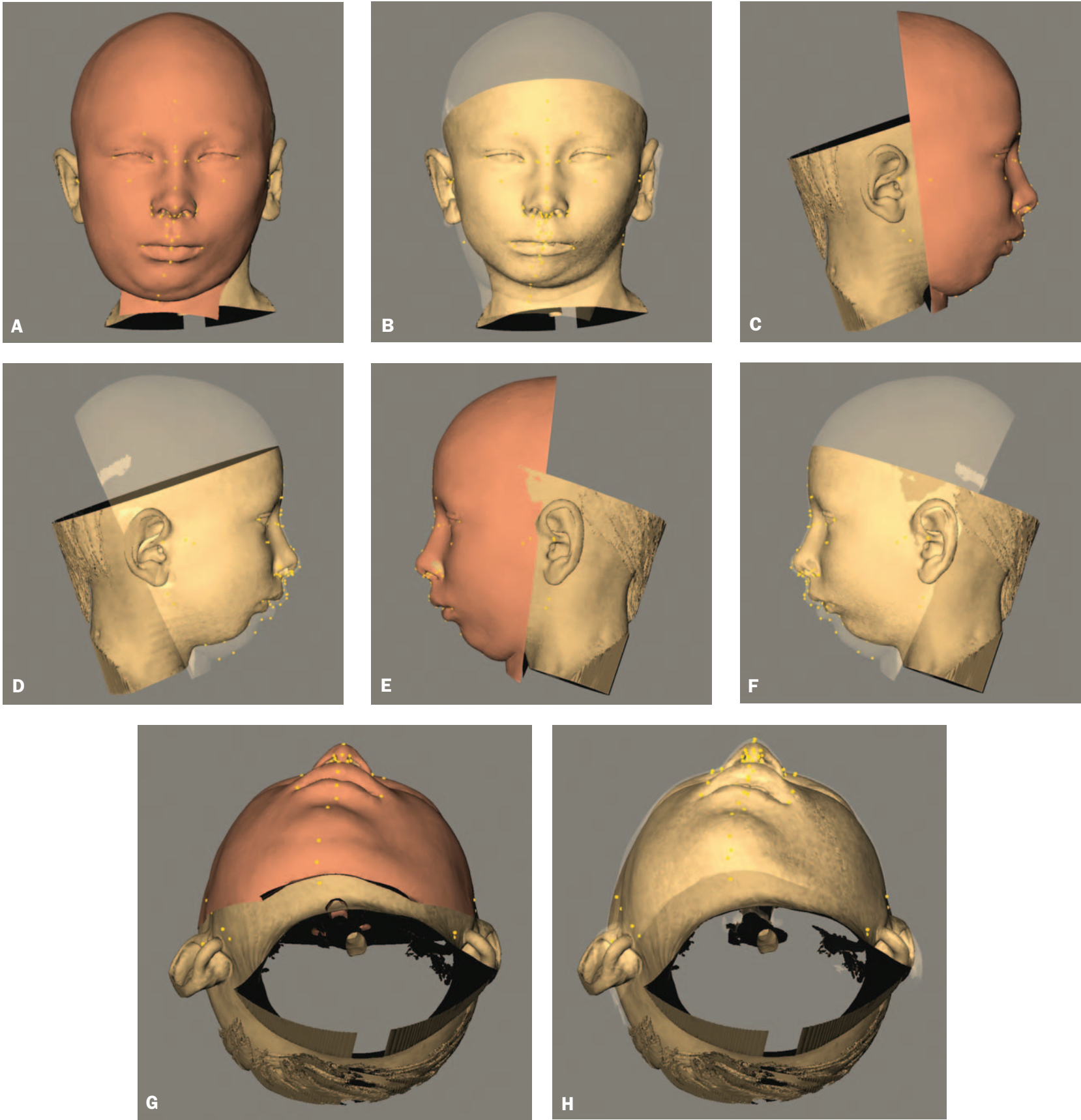


FIGURE 6-46 Multi-slice computed tomography scan of Patient B.R. Same patient as in Figure 6-9. Superimposition on the three-dimensional cephalometric reference system of the preoperative and postoperative long-term (1 year after distractor removal) soft tissue surface representations (Maxilim, version 2.0, Medicim NV, Belgium).

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Analytic Model Surgery

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Surgical movements of the jaws are complicated three-dimensional problems of geometrically complex structures. The diagnostic information gained from preoperative clinical and radiographic examinations and models must be carefully integrated to establish a surgical treatment plan. The final treatment “prescription” is expressed in the model surgery. Model surgery will both allow confirmation of the surgical plan and provide the surgeon with quantitative information for use in the operating room. This chapter will introduce and review techniques for accurately orienting and measuring maxillary and mandibular surgical models.

Surgical correction of dentofacial deformities involves a complex series of surgical and non-surgical procedures. Dentofacial deformities, whether developmental or acquired, require a careful and thorough evaluation of the structural and functional problems associated with them. Restoration of normal jaw function, the proper three-dimensional placement of the jaws within the face, and long-term stability of the surgical result are all important features of successful treatment.¹⁻⁴

Conceptually, treatment planning—and therefore model surgery procedures—can be broken down into three general treatment categories or schemes. These categories are mandibular surgery, maxillary surgery, and two-jaw surgery. Surgical treatment for any given patient should be individualized and should take full advantage of a surgeon’s skill and knowledge. The surgeon has a large number of proven surgical procedures and combinations of procedures to choose from. Yet, even when combinations of procedures are prescribed, the final treatment planning decisions made by the surgeon consistently fall into one of the above three categories. These categories, by their nature, are functionally determined.

The goals of dentofacial surgery can be summarized as follows:

- To establish the optimal functional relationship between the maxilla and mandible.
- To place the jaws optimally, in three planes of space, within the facial skeleton.

Deformities of the jaws invariably have both functional and esthetic components. The finest

surgeons strive to fulfill goals pertaining to both of these components. An excellent surgical orthodontic result will establish an excellent occlusion, with the condyles optimally seated with the glenoid fossae. In addition, the jaws will be positioned to correct the structural abnormalities responsible for the patient’s esthetic problems.

Presurgical Database

Careful planning requires a systematic approach to define a patient’s deformity and establish a treatment plan. The surgeon must first acquire the necessary diagnostic information from which he/she will make treatment planning decisions. The primary components of the presurgical database are the clinical examination, lateral and anteroposterior cephalometric radiographs, and the articulator-mounted models. Important secondary components are panoramic and periapical radiographs (for interdental osteotomies) and facial and intraoral photographs (Table 7-1).

A thorough clinical examination will provide the surgeon with an overview of the patient’s deformity and important quantitative information. Functional problems related to the patient’s temporomandibular joints and malocclusion are recorded. The surgeon must note not only the symmetry of the jaws but also the symmetry of other important structures, such as the eyes and ears. A critical evaluation will show that all patients have some degree of asymmetry. In a frontal plane, the clinician must make decisions related to a patient’s facial midline. From this

assessment, judgments will be made on the acceptability of the midlines of the mandible and maxilla. Crucial quantitative information gained from a clinical frontal analysis of a patient includes measurements of maxillary and/or mandibular cant and tooth-to-lip relationships. A small millimeter ruler, such as a Boley gauge, is very useful in making these measurements. Cant is usually measured with the patient in a supine position. The ruler is used to measure the vertical distance between the cuspids and the medial canthus bilaterally. The surgeon integrates these measurements with an assessment of the symmetry of the eyes and such factors as the characteristics of the patient’s smile. When tooth-to-lip measurements are made, the patient’s lips must be in repose. This is best done with the patient in a standing position. The clinical tooth-to-lip measurement will be correlated with the same measurement made from the lateral cephalometric radiograph. Clinical measurements are generally better, as the surgeon has the opportunity to ensure that the lips are in repose and even remeasure if necessary.

In examining the profile, the clinician will assess the anteroposterior position of the maxilla and mandible. As in the frontal examination, the clinician will evaluate the skin drape over the facial skeleton. In the frontal plane, the clinician establishes a clinical midline and integrates diagnostic information in relation to that reference line.

Upper lip support is an important clinical feature. An assessment of upper lip support will provide the clinician with information regarding the proper anteroposterior position of the maxilla relative to facial soft tissues. White rope wax can be molded and placed under the upper lip to estimate the effect of maxillary advancement (at the level of the tooth and the A point) on the soft tissues of the upper lip and base of the nose. The thickness of the wax can be measured and will provide the clinician with a quantitative estimation of the patient’s ability to tolerate forward positioning of the upper jaw. Similarly, patients with mandibular deficiency may be asked to position their mandible forward.

Presurgical radiographs and photographs are also important parts of the patient’s presurgical

Table 7-1 Presurgical Database

Primary Components

Clinical examination (profile and frontal evaluation)
Cephalometric radiographs (lateral and anteroposterior)
Anatomically mounted models (full-sized articulator)

Secondary Components

Panoramic radiograph
Periapical radiographs (interdental osteotomies)
Photographs (facial and intraoral)

database. Facial photographs and cephalometric radiographs are taken with the patient holding his/her head in the same position. Teeth are in light contact and in centric relation. Soft tissues are in repose. Because natural head posture is remarkably constant, and reproducible, clinical and cephalometric examinations are made with the patient's head in the adjusted natural head position.^{1,5} While sitting or standing at ease, the patient is asked to look into the reflection of his/her eyes in a mirror positioned at eye level. Such records are best taken by a surgeon who will be involved with the actual surgery and who will do the cephalometric planning and model surgery procedures. A natural horizontal reference line derived from the posturally oriented lateral cephalogram is drawn on acetate tracing paper, and a vertical reference line is constructed perpendicular to it through the subnasale. A careful correlative analysis of the patient's features and the lateral cephalogram is made to determine if the true natural horizontal plane (HP) and Frankfort horizontal (FH) are parallel or nearly parallel to each other. If so, both frontal and profile views of the patient may be oriented so that the FH is parallel to the floor (HP). If there is a significant difference between the HP and FH, then the natural reference HP is used. The clinician must be particularly careful in planning the treatment of patients with dentofacial or craniofacial deformity, because the FH in such patients may not coincide with the natural HP.

Additional lateral cephalometric radiographs and photographs may be taken to record the results of clinical tests such as forward positioning of a deficient mandible or placement of wax under the upper lip in the case of a deficient maxilla. Frontal facial photographs (of the patient in repose and while smiling) and an anteroposterior cephalometric radiograph will provide important information regarding asymmetry, which will be compared with the results of the clinical examination.

Perhaps the most commonly underused component of the database is the articulator with anatomically mounted models. When properly mounted on a full-sized anatomic articulator, presurgical models offer a wealth of information. Mounted models will simulate the patient's facial structure both functionally and spatially. It has, however, been difficult to quantify this information. The Erickson Model Platform (Great Lakes Orthodontic Products, Ltd, Tonawanda, NY) is an instrument that is designed to measure articulator-mounted models accurately in three planes of space. This feature allows the surgeon who is planning treatment to define the three-dimensional position of both the maxillary and the mandibular models. With this instrument, the mounted models can be correlated with the cephalometric radiographs and the clinical examination.

A Common Reference Plane

Perhaps the most important principle in integrating diagnostic information is the establishment of a common reference plane. As an example, one can consider a patient who will have two-jaw surgery for correction of a deformity. Two-jaw surgery is the most complex of the three treatment schemes. Treatment planning for two-jaw surgery is one of the most challenging topics in oral and maxillofacial surgery.^{3,4} In such cases, the surgeon has determined that a significant deformity exists in both the maxilla and the mandible.

In planning a two-jaw surgical procedure, the surgeon spends much of his/her time determining the new three-dimensional position of the maxilla. Cephalometric radiographs are used in two different ways during a patient's work-up. First, an "analysis" is done. The surgeon measures angles and makes quantitative measurements. These studies are diagnostic in nature. Second, cephalometric radiographs are used for making prediction tracings. The surgeon performs "trial surgery" with acetate overlays to test treatment options. Excellent material is available on prediction tracing procedures, and the topic will be addressed only conceptually in this chapter.⁵⁻⁷

In our example, let us assume the surgeon decided to raise the maxillary central incisor by 3.0 mm (vertical change), to advance the incisor by 4.0 mm (anteroposterior change), and to move the maxillary dental midline 2.0 mm to the right (transverse change) (Table 7-2). The surgeon has also decided to raise the posterior of the maxilla at the second molar by 3.0 mm. The presurgical maxillary cant (relative vertical position of cuspids) and arch rotation (relative anteroposterior position of cuspids) have been evaluated and were found to be acceptable. The surgeon chose to make no differential change of the cant or arch rotation. These six decisions will determine the spatial position of the maxilla (and therefore the mandible). The clinician has made these quantitative decisions based on material gathered from the presurgical database.

The decision to raise the maxillary central incisor is based on a finding of vertical maxillary excess or hyperplasia. The surgeon has used the central incisor as a "landmark" in determining

that the anterior maxilla is too long. Generally, the surgeon will make this determination from a lateral prediction tracing on a well-oriented cephalometric radiograph and a frontal clinical examination. The decision to move the incisor (again, a landmark) forward by 4.0 mm is primarily based on the prediction tracing and the profile or lateral clinical examination. The decision to change the dental midline, moving it 2.0 mm to the right, will be based mainly on the frontal clinical examination with perhaps some input from the anteroposterior radiograph. The decision to keep the same maxillary cant and maxillary arch rotation or to change them will rest on information from the clinical examination, radiographs, and anatomically mounted models. In all cases, whether hypothetical or with a patient who requires a far more complex movement, treatment decisions are based on multiple sources of information, individualized considerations, and the therapist's "esthetic sense" of facial beauty and proportion.¹

It is critical that the concept of a common reference plane, linking the primary components of the presurgical database, be understood and used in planning. Without a common plane of reference, it is impossible to integrate the primary components of the database accurately and reliably. The FH represents a logical common reference plane. It is an anatomic plane that is defined by the porion and orbitale. Clinically, the bony points can be closely estimated, and the patient's head can easily be oriented to a natural horizontal position. The HP, as described by Bell and Jacobs, is a natural head position that, in the majority of patients, is clinically comparable to the FH.^{1,5} If the HP and FH are parallel or nearly parallel to each other, then the use of the FH is valid as a common reference plane in assessing clinical, cephalometric, and model surgery studies. When the patient's models are mounted on a full-sized anatomic articulator, a face-bow is used to orient the maxillary cast to the upper member of the articulator. The face-bow "registers" and "transfers" to the articulator the three-dimensional relationship of the patient's maxilla to the cranium. Face-bows are oriented to a patient's intercondylar axis (rather than the porion) and orbitale. Mounted models are oriented, by

Table 7-2 Hypothetical Case: Treatment Prescription		
Dental Landmark	Plan	Amount and Direction of Desired Change
Maxillary central incisor	Vertical	3.0 mm superior
Maxillary second molar	Vertical	3.0 mm vertical
Maxillary cuspids	Vertical	Differential movement to be unchanged
Maxillary central incisor	Anteroposterior	4.0 mm forward
Maxillary cuspids	Anteroposterior	Differential movement to be unchanged
Dental midline	Transverse	2.0 mm to right

definition, to the axis-orbital plane (AOP). Ricketts has found that the top of the condyles is usually very close to the true porion. Class III patients may have their condyles just above the porion, whereas Class II patients may have their condyles just below the porion. When models are properly mounted on an anatomic articulator, their AOP orientation is essentially identical to the FH. It is helpful to think of the AOP as the Model Frankfort (MF).

Information from the three primary components of the presurgical database—the clinical examination, the cephalometric radiographs, and the anatomically mounted models—can be integrated, with the FH serving as a common reference plane (Table 7-3 and Figures 7-1 through 7-3). The concept of a common reference plane is fundamental to accurate evaluation and treatment planning.

Table 7-3 Frankfort Horizontal: The Common Reference Plane*	
Examination	Reference Plane
Clinical examination (profile)	Frankfort horizontal (FH)
Clinical examination (frontal)	Frankfort horizontal
Cephalometric radiograph (lateral)	Frankfort horizontal
Cephalometric radiograph (anteroposterior)	Frankfort horizontal
Articulator-mounted models (lateral)	Axis-orbital plane (MF)
Articulator-mounted models (anteroposterior)	Axis-orbital plane (MF)

*For the FH to be a clinically useful common reference plane, the FH and horizontal plane (HP) must be parallel or nearly parallel.

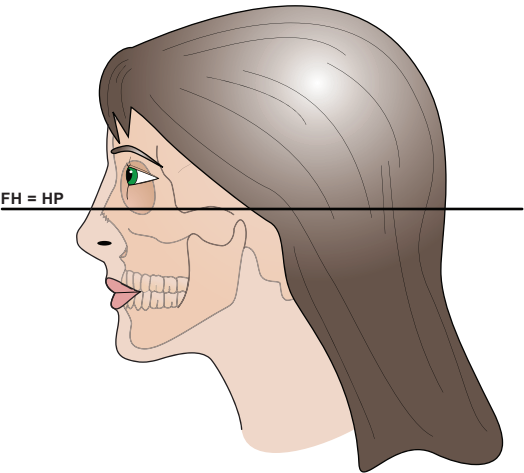


FIGURE 7-1 The Frankfort horizontal (FH) serves as a reference plane for the clinical evaluation of the patient. It also serves as the common reference plane for all phases of presurgical planning.

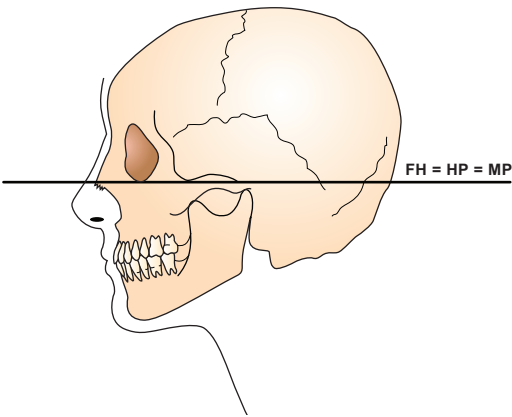


FIGURE 7-2 The cephalometric radiograph and prediction tracings are oriented to the Frankfort horizontal.

Mounting Dental Models for Surgery

Dentofacial surgery, even at its best, does not require the use of a fully adjustable articulator. A strong case, however, can be made for making the use of an anatomic articulator (semi-adjustable) the standard. If possible, the articulator should be able to accept both an arbitrary and a hinge-axis face-bow mounting. The use of an anatomic articulator by the surgeon involved in treatment planning allows the manipulation of the maxillary and mandibular models in three planes of space within the articulator. When the models are correctly mounted, this manipulation will be analogous to surgical movements of the jaws within the facial skeleton. The functional and esthetic implications of this procedure are clear.

In addition, an anatomic articulator is the three-dimensional analogue of the two-dimensional cephalometric radiograph. Mounted

models offer the significant advantages of a third dimension and exactness to scale. Stone models are a 1:1 representation of the patient’s facial structure, whereas cephalometric radiographs are inherently distorted by some degree of enlargement (usually on the order of 10%).

In the near future, computed tomography (CT) scans using software capable of producing three-dimensional images will be widely available and will offer the great advantage of a 1:1 image. Currently, work is being done on correlating model surgery movements with computerized cephalometric analysis and prediction tracing techniques and model surgery will be exciting.

In mounting dental models on an anatomic articulator, the purpose of any face-bow transfer procedure is to reproduce accurately the functional and spatial relationship of the jaws. All transfer techniques attempt to obtain a hinge-axis mounting.

With a *hinge-axis face-bow* transfer, special techniques are used to ensure that the intercondylar axis of the patient coincides with the intercondylar axis of the articulator. The “arc of closure” of the mandibular model on the articulator will very closely simulate the real mandibular arc of closure over a given range. The clinician verifies the accuracy of the hinge mounting with a series of check bites (simulating increasing degrees of opening) and split cast mountings. The third point of reference for a hinge-axis mounting is the inferior orbital rim. The models are, by definition, mounted to the AOP. As noted previously, this plane is formed by the intercondylar axis and the lowest point on the inferior orbital rim or orbitale. For practical purposes, this plane is essentially identical to the FH.

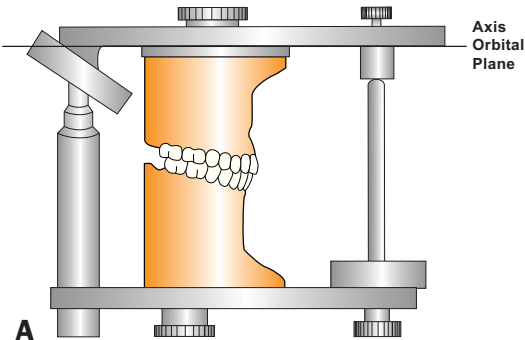
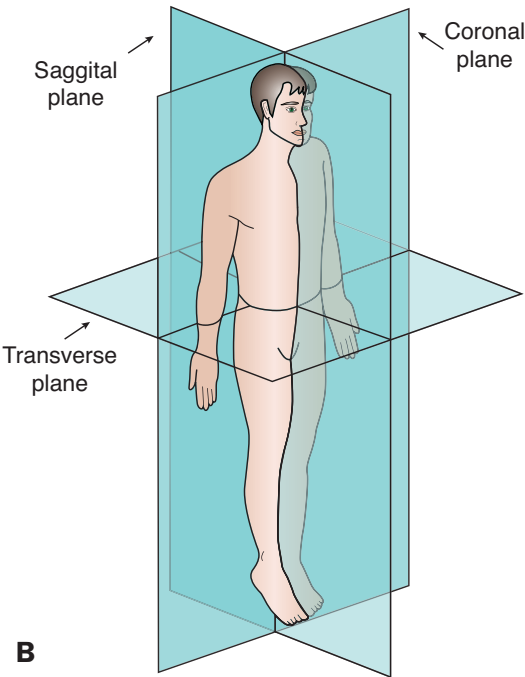


FIGURE 7-3 Articulator-mounted models are oriented to the axis-orbital plane (A). This plane is essentially equal to the Frankfort horizontal (B). The authors refer to the axis-orbital plane as the Model Frankfort (MF).



Some clinicians would argue that a hinge-axis transfer should be done in all cases of total maxillary surgery, whether isolated or in combination with mandibular surgery. The greater the vertical change (vertical maxillary change and increased mandibular autorotation), the more important a hinge-axis mounting becomes. If a mounting is significantly “off” from the patient’s arc of closure, the incorrect autorotation from the articulator will result in an error in the planned placement of the patient’s maxilla. This error may manifest itself as an error in the midline, cant, vertical placement, or anteroposterior positioning of the maxilla. If, however, the mounting is off and there is little vertical change, then there will be less potential for error related to an incorrect mounting.

In most cases, models can be mounted with an *arbitrary face transfer* without compromising results. Arbitrary mountings are usually related to a patient’s ears rather than specifically to the patient’s intercondylar axis. This procedure is less complicated while locating the jaws anatomically within the articulator in a satisfactory manner.

When the operation involves the mandibular ramus, the mandible is separated into proximal and distal segments. The final condylar position is influenced by many factors. These factors include the surgeon’s ability to place the condyle optimally at the time of surgery, the surgeon’s clinical experience and ability to plan dentofacial surgery, the degree of condylar rotation or movement within the joint cavity (in all three planes of space), joint health, and the stabilization technique appropriate for the patient.

In isolated mandibular surgery, a hinge-axis transfer will have no advantage over an arbitrary face-bow mounting. When used in conjunction with the Erickson Model Platform and Model Block (Great Lakes Orthodontic Products, Ltd), an anatomic mounting for isolated mandibular surgery will allow an accurate correlation between jaw movements on the prediction tracing and those on the mandibular model.

The surgeon must have an understanding of the basis of either mounting. A hinge-axis mounting may help the surgeon to provide a more accurate representation of the functional relationship of the mandible to the maxilla. Condyles, however, are never perfectly symmetric. This mounting, based on the condyles, is not a reliable baseline for esthetic decisions. An arbitrary mounting related to the ears may be no better. Ears, like any paired anatomic structures, may be asymmetric and thus may provide a poor baseline for decisions related to the surgical movements of the jaws.

It is important for the clinician to review the mounting critically. The standard SAM arbitrary face-bow (SAM Co, Munich, Germany) had several deficiencies when used for surgical cases.

The third point of reference (the ear canals serve as the first two) of the face-bow is the nasal rest. This point of reference stabilized the face-bow while the bite-fork registered the three-dimensional position of the maxillary arch. The vertical position of the nasal rest was not adjustable and led to systematic errors in mounting. The occlusal plane of the maxillary model was commonly too steep. With the maxillary cast too steep, a common reference plane did not exist between the models and the other primary components of the work-up. The SAM face-bow has been modified, and a new version is available for surgical use (Great Lakes Orthodontic Products, Ltd). The modifications of the surgical face-bow include an adjustable nasal rest and infraorbital pointer. The vertical position of the nasal rest is adjustable. The final vertical position of the nasal rest is guided by an infraorbital pointer fastened to the horizontal bar of the face-bow (Figures 7-4 and 7-5). Although it is important to check mountings on individual cases, this has largely solved the previous problem.

The clinical examination will always be essential for interpreting both mounted models and cephalometric information. As an example, a patient may clinically have a level anterior maxilla in an HP, while on an accurately mounted articulator model there may be a significant cant. In such a case, the surgeon would continue to use the articulator (reflecting an asymmetry in the hinge-axis or arbitrary mounting) but treat according to the clinical examination.

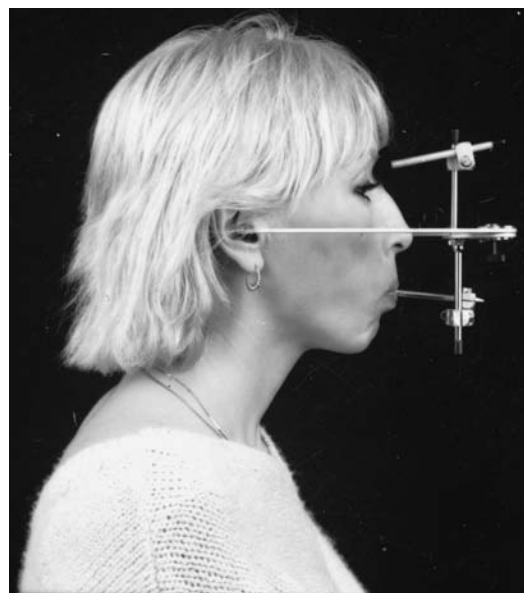


FIGURE 7-4 The modified SAM face-bow (Great Lakes Orthodontic Products, Ltd, Tonawanda, NY) has an adjustable nasal rest and is used in surgical cases. The occlusal plane of the maxillary models mounted with the standard SAM face-bow (Great Lakes Orthodontic Products, Ltd, Tonawanda, NY) is frequently too steep.



FIGURE 7-5 An infraorbital pointer has been added to the modified SAM face-bow (Great Lakes Orthodontic Products, Ltd, Tonawanda, NY) and is the third point of reference. The nasal rest stabilizes the face-bow.

Care should be taken in either case to mount the maxillary model as close as possible to the true natural horizontal plane (HP; $HP = FH$). This practice will allow a common reference plane for interrelating the mounted models with the cephalometric prediction tracing. The degree to which the HP of the prediction tracing and the ($HP = FH$) of the mounting correspond will affect the accuracy of the final model surgery and ultimately will transfer the planned movements to the surgical site. These plans are facilitated by the use of an extraoral vertical and anteroposterior referent system.

The mandibular cast must always be mounted to (related to) the maxillary cast, with attention paid to the position of the mandibular condyles. A centric occlusion position—a solely tooth-dictated position—is frequently habitual rather than anatomic and is insufficient. When mounting the mandibular model, a wax-bite registration is taken that relates the mandible to the maxilla independent of the occlusion. The mandible is carefully manipulated so that the condyles are placed anteriorly and superiorly within the glenoid fossae. The surgeon’s clinical experience, skill, and “art” are vital in obtaining an accurate centric-relation wax-bite registration. In most cases, an accurate condylar position (centric relation) can be obtained with the use of a leaf gauge or a presurgical occlusal splint.^{8,9} If the mandible is difficult to manipulate and the surgeon is unable to determine its presurgical centric-relation position, it may be necessary to sedate the patient and place him/her in a supine position for this registration. During surgery, the patient will be relaxed and frequently fully paralyzed. Placement of the condyles at the time of surgery is arguably the most critical point in the patient’s surgical treatment. The final condylar position and the surgical result will depend on the surgeon’s accuracy in planning and his/her skill at the time of surgery.

Prediction Tracings and Model Surgery: An Analogy

Model surgery is both a component of the surgeon's preparation and a product of it. The primary goal of model surgery is to accurately simulate the patient's facial structures both functionally and spatially. Mounted models can be used to predict hard tissue changes in much the same way as do prediction tracings. With models, there are several very important advantages. Prediction tracings are limited to two dimensions and are inherently distorted. Conventional cephalometric radiography equipment produces images that are generally 10% enlarged. Dental models are a 1:1 representation of the patient's facial structures, and have the added advantage of the third dimension.

To understand the model surgery technique described in this chapter, it is important first to understand prediction tracing techniques. Presurgical cephalometric radiographs are used to make prediction tracings. Cephalometric radiographs were developed to study growing patients. The usefulness of these images as a diagnostic tool soon became evident.¹⁰ Ricketts was the first to recognize the clinical implications of abnormal facial growth patterns.¹¹

When making a prediction tracing, the planning surgeon will manipulate two-dimensional drawings, or "cut-outs," of the maxilla or mandible or both. Prediction tracings allow the surgeon to perform trial surgery and test the potential benefits of a particular surgical plan. In the case of isolated mandibular surgery, the distal mandible is positioned in its estimated postsurgical position with the maxilla. In isolated maxillary surgery, the estimated occlusal relationship between the maxilla and mandible is established, and the maxilla is autorotated on a mandibular tracing, around the hinge axis of the mandible, to its planned vertical position. In two-jaw surgery, the surgeon first places the maxilla in its new position and then brings the mandible to it.

Prediction tracings allow the planning surgeon to estimate both dental and bone changes. In the case of two-jaw surgery, the surgeon may wish to change the vertical and anteroposterior positions of the incisor teeth. By manipulating the prediction tracing cut-out, the surgeon can change both the tooth-to-lip relationship and the upper lip support. Vertical changes of the second molars in combination with vertical changes of the incisors will determine the occlusal plane. The planning surgeon uses *dental landmarks*, in this case molars and incisors, to place the maxilla in its new position. By changing the position of strategic teeth, the surgeon is able to satisfy specific treatment planning goals.

As cut-outs are repositioned on the cephalometric tracing, it is evident that the resultant *bone changes* can be calculated. When the maxilla is

moved vertically, there will be an overlap of the upper and lower portions of the maxilla on the prediction tracing. This overlap allows the surgeon to estimate the amount of bony contact expected at the time of surgery. The specific characteristics of the case will determine if this bone has to be actually removed. Anteroposterior bone changes can be calculated as well. In open-bite cases, the posterior maxilla frequently undergoes a greater vertical change than does the anterior maxilla. This type of movement will cause the maxilla to tip forward (rotate in a clockwise fashion), leading to an anteroposterior change in the A point, even in the absence of an anteroposterior change in the incisor. Any surgical movement, whether in the maxilla or the mandible, will result in both dental and bone changes.

During model surgery procedures, the same process is repeated. The surgeon uses information gained from the work-up to carry out trial surgery on the models. The surgeon uses strategic teeth as dental landmarks to satisfy treatment goals. Mounted models can be used to predict bone changes in the same way as prediction tracings, but with much improved accuracy. During prediction tracing procedures, the surgeon manipulates jaw cut-outs on a two-dimensional distorted (enlarged) field. During model surgery, the surgeon manipulates a 1:1 cast of a patient's jaw or jaws in three dimensions.

The Model Platform and the Model Block

The Erickson Model Platform and the Model Block (Figure 7-6) are capable of accurately measuring articulator-mounted models in three planes of space. This feature allows the planning surgeon to carry out accurate model surgery movements on a full-sized anatomic articulator. In addition, the surgeon is able to coordinate, in a meaningful manner, mounted models with

the clinical examination and cephalometric radiographs.

The Model Platform is a measuring instrument. Its base is tool-grade granite with a very smooth and even surface. The surface is manufactured to be level to a tolerance of 0.001 inch. Inserted into the granite base is an electronic caliper. The caliper is positioned at 90° to the granite base. The caliper is able to make metric measurements to an accuracy of 0.01 mm. The calipers can be used to scribe delicate lines on plaster or stone models. The caliper is a precision instrument and must be used in an appropriate manner.

The Model Block is an orientation block that is used with the Model Platform. Models are mounted on the Model Block in the same way that they are mounted on a full-sized articulator. Dental casts are attached to the block with a mounting screw and are positioned in a reproducible manner with indexing pins. Pin indexing systems for different articulators vary. Model Blocks are available for each of the various systems. The Model Platform can be used with any of these Model Blocks and therefore any full-sized articulator. The block is made of anodized aluminum and is manufactured to the same level of tolerance as that for the platform base. The top and bottom of the block are parallel. All angles are exactly 90°. The precision of the instrumentation allows for the measurement of models to a full order of magnitude greater than would ever be required clinically. This precision, as well as other characteristics of its construction, eliminates the platform as a potential source of error in model surgery procedures.

Planning dentofacial surgery is a complex process. The planning surgeon must be aware of potential sources of error and should attempt to minimize, if not eliminate, them. Errors related to model orientation (reference plane) have already been discussed. Measurement errors, a second

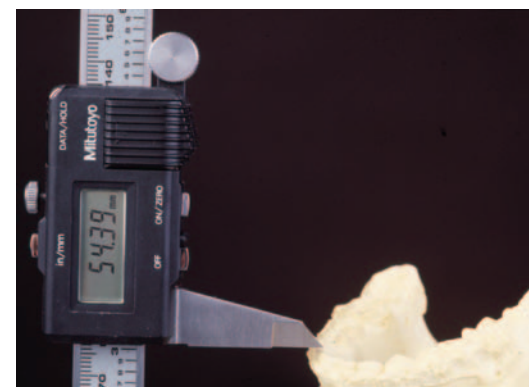
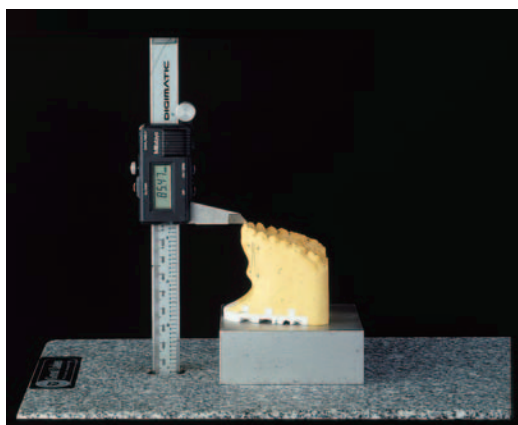


FIGURE 7-6 Left and right, The Erickson Model Platform and the Model Block (Great Lakes Orthodontic Products, Ltd, Tonawanda, NY) are used to measure articulator-mounted models in three planes of space. Vertical, anteroposterior (AP), and transverse measurements are made by changing the orientation of the Model Block on the platform base.

category, are primarily due to problems related to instrumentation and perspective. Hand-held millimeter rulers have commonly been used in model surgery procedures. As measuring instruments, these are inadequate for several reasons. The first problem is their lack of precision.

Dentofacial surgery is performed on the order of millimeters. Surgical movements, in general, range from 1 to 10 mm in any given plane of space (in unusual circumstances, movements may be greater, particularly in anteroposterior movements of the mandible). Although a simple millimeter ruler may be sufficient to measure model surgery movements at the upper end of this range, it is clearly inadequate to measure movements accurately at the lower end. With model movements of 8 to 10 mm, a 1 mm error (the smallest unit of measurement on this type of ruler) will result in an overall error in the area of 10 to 12%. This degree of error may be acceptable, when it will not lead to a significant clinical problem. If, however, a 1 mm measurement error occurs when the surgeon wishes to make a 1 or 2 mm movement, then the error is on the order of 50 to 100%! A vernier caliper, such as a Boley gauge or Beerendonk caliper (Great Lakes Orthodontic Products, Ltd, Tonawanda, NY), is a great improvement over a simple millimeter ruler, since it is able to measure more accurately—to 0.1 mm. This improved accuracy makes little difference in making large model movements but is helpful in smaller movements.

The second major problem with hand-held rulers is parallax error. Parallax error is an error in viewing perspective. When a ruler is held against a model, the surgeon must view the ruler and object in a consistent manner. To compare pre- and post-model surgery measurements, the surgeon must not only hold the ruler in exactly the same position, but must also view the ruler and model from exactly the same perspective. A vertical change in perspective (a change in the level of the surgeon's eye relative to the ruler) will lead to a reading on the ruler that will either underestimate or overestimate the actual measurement.

These measurement problems are solved with the Model Platform and Model Block. The Model Block will accurately transfer the orientation of the model to the measuring platform. With the Model Block on its base, reproducible vertical measurements can be made; with the Model Block on its end, reproducible anteroposterior measurements can be made; and with the Model Block on its side, reproducible transverse measurements can be made. By manually changing the Model Block on the platform, the surgeon can quickly measure and remeasure any point of interest, either dental or bone, on the cast. The electronic caliper inserted into the base of the platform is able to obtain an appropriate level

of precision (0.1 mm is recommended by the authors) and is free of parallax error.

Treatment Schemes and Surgical Prescriptions

A surgeon's treatment plan will fit into one of three general treatment categories, or schemes. In each treatment scheme, a systematic and reproducible approach to model surgery is possible. After the surgeon has chosen the procedure or procedures necessary to correct a patient's deformity, he/she will be able to identify the appropriate model surgery technique. Decisions related to chin surgery are independent of the three treatment schemes.

Treatment Scheme I: Functionally Isolated Mandibular Surgery

When mandibular surgery alone is chosen by the surgeon, he/she has made a decision to accept the three-dimensional position of the maxilla as a template. All procedures and combinations of procedures in this group depend on the maxillary template. In the most simple treatment plans, the mandible will be moved forward in the case of anteroposterior deficiency, or set back in the case of mandibular prognathism. Patients in this treatment category will have some form of mandibular ramus surgery.

A more complex combination of procedures would include mandibular subapical surgery or any form of chin surgery or both. Combinations of mandibular ramus surgery with maxillary segmental surgery would also be included. As long as some portion of the maxilla remains structurally intact, it will continue to serve as a template for positioning of the mandible being operated upon. This is a subtle but important point in understanding surgical planning.

An example would be a patient with a Class II skeletal deformity (mandibular anteroposterior deficiency) and a narrow but otherwise normal maxilla. Following presurgical orthodontic treatment, the patient's maxilla has a residual deformity. To provide for an optimal occlusal relationship, a posterior segmental osteotomy will be performed to widen the maxilla. Even though this segmental osteotomy will be performed, the three-dimensional position of the maxilla remains intact. From a planning standpoint, the maxilla continues to serve as a template for positioning the mandible. Planning for procedures that include maxillary segments in addition to mandibular ramus surgery is conceptually the same as planning for isolated mandibular surgery alone.

An additional group of surgical procedures that are less commonly performed belong to this category under certain circumstances. These are body osteotomy and ostectomy procedures. This

subcategory may include bilateral mandibular body osteotomy or ostectomy procedures or an anterior mandibular subapical osteotomy performed in combination with a midline osteotomy if the procedures can be accomplished without total (Le Fort I) maxillary surgery. In both of these examples, the three-dimensional position of the mandible is determined by the maxillary template.

Surgical Prescription for Treatment Scheme I.

When choosing Treatment Scheme I, the surgeon does not make a further decision affecting the final three-dimensional position of the mandible.

When segmental maxillary surgery is performed in combination with mandibular surgery, model surgery establishing the mandibular arch is completed prior to work on the maxillary cast.

In summary, Treatment Scheme I includes those procedures or combinations of procedures that depend on a structurally intact maxilla or a portion of a maxilla to serve as a template for mandibular surgery. The maxilla or a portion of the maxilla will determine the anteroposterior, vertical, and transverse positions of the mandible.

Treatment Scheme II: Functionally Isolated Maxillary Surgery

In Treatment Scheme II, the surgeon has made a decision to accept the mandible as a template for three-dimensional positioning of the maxilla. Once again, the surgical treatment plans may range from simple to complex. In this treatment scheme, however, the mandibular template can position the maxilla in only two of the three planes of space (anteroposterior and transverse). The surgeon is obligated to position the maxilla being operated upon in the correct vertical position.

In the majority of cases that fall into this category, total (Le Fort I) maxillary surgery will be performed. In a basic treatment plan, a patient with a maxillary deformity would be treated with a Le Fort I osteotomy. From a conceptual standpoint, there is little difference between one-piece and multiple-piece maxillary surgery. The mandible, through the occlusion, will determine the anteroposterior and transverse (width and midline) positions of the maxilla. The surgeon must decide on vertical placement of the maxilla. In the case of maxillary vertical excess, an ostectomy will be performed. In the case of vertical deficiency, the patient may require grafting. Vertical reference techniques and surgical experience allow for accurate placement of the maxilla.

As in Treatment Scheme I, variations of greater surgical complexity fall into this category. Segmental mandibular surgery, such as anterior subapical surgery, may be performed without changing the mandible's role as a template.

Surgical Prescription for Treatment Scheme II

When choosing Treatment Scheme II, the surgeon must decide on *vertical* placement of the anterior maxilla (tooth-to-lip determination).

When segmental mandibular surgery is performed in combination with total maxillary surgery, model surgery that establishes the mandibular arch (thus establishing the template) is completed prior to work on the maxillary cast.

In summary, Treatment Scheme II includes those procedures or combinations of procedures that depend on a functionally intact mandible to serve as a template for maxillary surgery.

Treatment Scheme III: Two-Jaw Surgery

The overall goal of dentofacial surgery is to restore normal jaw function, provide for long-term stability, and esthetically position the jaws within the face. In many cases, these goals cannot be met without operating simultaneously on the maxilla and mandible.

Two-jaw surgery is the most complex combination of procedures from a planning standpoint. In such cases, the surgeon has determined that a significant deformity exists in both the maxilla and the mandible. The issue of treatment planning for two-jaw surgery is one of the most interesting topics in oral and maxillofacial surgery.

When the surgeon has decided that neither the mandible nor the maxilla is in an acceptable position, he/she will have used specific criteria to make these judgments. Careful and systematic clinical, cephalometric, and occlusal examinations are necessary. The surgeon will analyze this information from both functional and spatial aspects. As an example, the surgeon may consider the vertical position of the maxillary incisors and cuspids (tooth-to-lip and maxillary cant relationships), the transverse problems of both tooth and bone positions (dental midline and chin positions), and anteroposterior dental or bone deformities.

Similarly, in treatment planning for the correction of a bimaxillary deformity, the surgeon must make decisions that guide him/her in correcting the patient's deformity. The first step in this process is to define the patient's deformity in three planes of space. This is most easily done with the use of an anatomic (full-sized) articulator. Correct face-bow transfer and centric-relation registration techniques will ensure that dental models are mounted accurately on an articulator. The Model Platform and Model Block are then used to quantify dental and bony points on the articulator-mounted models.

In two-jaw surgery, either by default or by design, the surgeon will make decisions related to placement of the maxilla and mandible in all three planes of space. The goal must be to make treatment decisions by design.

In planning two-jaw surgery, the method used by most surgeons is first to place the maxilla (or maxillary cast in model surgery procedures) in the desired position and then bring the mandible to it. In choosing to perform two-jaw surgery, the surgeon has determined that neither jaw will serve as an acceptable template in correcting the patient's deformity. The surgeon must make treatment decisions related to the three-dimensional placement of the maxilla and, through that, the placement of the mandible.

Surgical Prescription for Treatment Scheme III.

When choosing Treatment Scheme III, the surgeon must make the following decisions:

- *Vertical* placement of the anterior maxilla (tooth-to-lip determination)
- *Vertical* placement of the posterior maxilla (vertical change of the second molars)
- *Vertical* changes of the right and left sides of the maxilla (maxillary cant, best measured at the cuspids)
- *Anteroposterior* position of the maxilla (anteroposterior change of the maxillary incisor)
- *Anteroposterior* changes of the right and left sides of the maxillary arch (arch rotation, best measured at the cuspids)
- *Transverse* placement of the midline of the maxilla (dental midline)

Thus, the surgeon will make three vertical decisions, two anteroposterior decisions, and one transverse decision.

The Model Platform is well suited to carry out the surgeon's prescribed treatment plan. The maxillary cast is seated on the Model Block. Pre-model surgery measurements will be recorded, quantifying important vertical, anteroposterior, and vertical measurements. The surgeon will establish a treatment plan and decide on specific (quantified in millimeters) surgical movements according to the above surgical prescription. By changing the orientation of the model on the Model Platform, the surgeon can quickly change from vertical to anteroposterior to transverse measurements. This allows the surgeon to change the maxillary cast accurately from its presurgical to its postsurgical position. This action is referred to as "floating" the maxillary cast. Once the maxillary cast is positioned so that the site criteria have been met, the mandible is moved to its new position. Post-model surgery measurements are made and correlated with prediction tracings.

When segmental surgery is performed (on either the maxillary or the mandibular models), it is important first to establish the mandibular arch and then the maxillary arch. In all cases of interdental osteotomy procedures, model surgery measurements are made directly on the casts. The most accurate information can be obtained if the models are trimmed anatomically.

In summary, in Treatment Scheme III, both the maxilla and the mandible are surgically moved. The surgeon has decided that neither the mandible nor the maxilla is in an acceptable position. Careful and systematic clinical, cephalometric, and occlusal examinations are necessary. The surgeon will analyze this information from both a functional and a spatial standpoint. The surgeon must make treatment decisions related to the three-dimensional placement of the maxilla and, through that, the placement of the mandible.

Measuring Final Models for Dentofacial Surgery

The *engineering principles* of model surgery must be sound. In performing model surgery, the surgeon must have a thorough understanding of jaw function and articulators. Full-sized articulators allow for accurate simulations of jaw function. Both the maxillary and mandibular models must be correctly mounted for this to be the case. The Model Platform and Model Block can aid in determining if the maxillary model is correctly mounted. Its primary role, however, is to measure articulator-mounted models in three planes of space.

If an object is to be moved in space (from one position to another), then an engineer will systematically quantify or define the object's initial position. The second step will be to determine the desired final position of the object. The third step will be to determine the three-dimensional movements necessary to accomplish the intended goal. In planning corrective jaw surgery, this same systematic approach can be very useful.

The position of an object in space is referred to as the *attitude* of the object. The attitude of an object is composed of its *pitch*, *yaw*, and *roll*. These familiar terms are not commonly used when discussing jaw deformities. Facial surgeons do, however, use synonyms routinely (Figures 7-7 and 7-8). Pitch is defined as the oscillation of the long axis of an object in the vertical plane. A change in pitch is a change in the *occlusal plane*. Yaw is defined as the oscillation of the long axis of an object in the horizontal plane. A change in yaw is a change in *arch rotation*. Finally, roll is defined as the rotation of an object in its longitudinal plane. Roll is synonymous with *cant*.

Measurements of jaw position are made in vertical, anteroposterior, and transverse planes. The clinician is very concerned with *tooth position*. Significant clinical findings associated with treatment planning include tooth-to-lip relationships, and cant, lip support, and midline considerations. It is important for the clinician to quantify the dental vertical, anteroposterior, and transverse positions of strategic teeth.

The clinician is also interested in changes in the *position of bone*. Movements of teeth *do not*

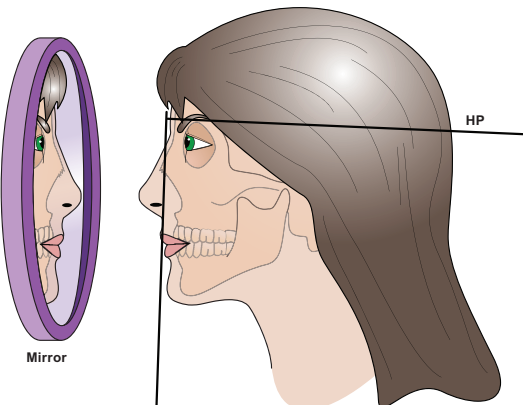


FIGURE 7-7 The attitude of an object in space is defined by its pitch, yaw, and roll. The spatial characteristics of any object can be quantified in a systematic manner.

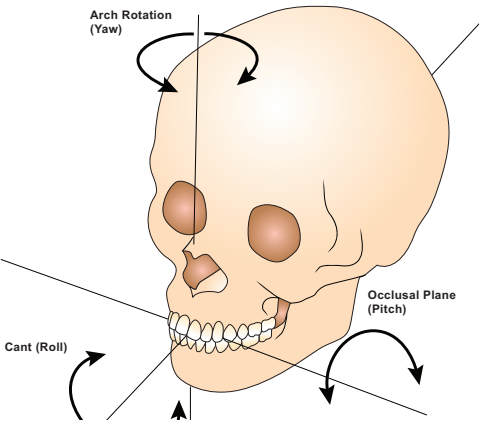


FIGURE 7-8 Pitch, yaw, and roll correlate to occlusal plane, arch rotation, and cant, respectively. The spatial characteristics of a dentofacial deformity are quantified and manipulated during model surgery procedures.

accurately reflect bone movements.¹² Surgical movements of the jaws are complicated three-dimensional problems of geometrically complex structures. Clearly, the surgeon needs to know bone changes while performing jaw surgery. This knowledge will allow the surgeon to make important clinical decisions related to bone removal and bone grafting requirements.

In summary, three-dimensional dental and bone measurements are needed to provide the

surgeon with optimal planning and intraoperative information.

Interdental Measurements

Accurate measurements of bone changes at interdental osteotomy sites can be made on the surgical models. From periapical radiographs (parallel technique), the *space available* (available bone) between the dental roots on either side of the osteotomy site is recorded. Measurements are made at the alveolar crest and apices of the teeth. A small hand-held vernier caliper, such as a Boley gauge or Beerendonk caliper, is needed for making these measurements. Well-oriented films will give accurate interdental information. Poorly oriented films will generally underestimate the actual space available between the roots. To obtain the most accurate measurements on the stone model, the buccal and lingual surfaces of the cast should be trimmed or sculpted to simulate the proper shape and dimensions of the alveolar bone.

1. Record “space available” measurements on a model surgery worksheet.
2. Trim the cast to simulate normal anatomy at the osteotomy site.
3. With a scalpel, scribe the long axis and the proximal root surface anatomy of each tooth on the stone; use the “space available” information to accomplish this.
4. With the scalpel, scribe an X or cross-hair over each tooth at the alveolar crest and at the level of the apex of the longest tooth; this is repeated on the lingual surface of the model; a felt-tip pen is helpful to highlight the X’s.
5. Measure the distance between the marks on the buccal and lingual surfaces of the model at the crestal and apical aspects and record these on a model surgery worksheet; these are presurgical interdental measurements.
6. Measurements are repeated following sectioning and setting of the segments; net changes are recorded and used at surgery.

Dental Vertical Measurements

These measurements are important for determining the presurgical and postsurgical vertical positions of important teeth. The authors recommend that central incisors, cuspids, and second

molars be measured and recorded. An example of a model surgery record sheet is shown in Figure 7-9. Dental vertical measurements of these teeth will give a starting point for making surgical changes in tooth-to-lip (incisors), cant (cuspids), and occlusal plane (incisors and second molars) relationships (Figures 7-10 and 7-11). Dental vertical measurements are always made on the maxillary cast. When isolated mandibular surgery is performed, the maxillary measurements are used to check the mounting. Mandibular dental vertical measurements are made and recorded only when the mandible is operated upon. These measurements are made on the Model Platform with the model mounted on the Model Block. The Model Block rests on its base. Measurements are usually rounded to the nearest 0.1 mm. Such precision cannot reasonably be obtained in a clinical setting. Model surgery systems, however, should have the ability to provide surgeons with planning information of a greater accuracy than that required at the time of surgery.

Model Surgery Record Sheet					
Name _____		incisal pin _____		feasibility _____	
				final _____	
Interdental		Bone	Vertical	Dental Vertical	
AP		Transverse			
right cuspid/nose		pre _____	post _____	net _____	
left cuspid/nose		pre _____	post _____	net _____	

These measurements are also important for interrelating the mounted models with the prediction tracings. The teeth and cusp tips essentially serve as discrete landmarks that can be identified on both the model and the cephalometric radiograph. Usually, lingual or distobuccal cusps are chosen on the second molars. The occlusal plane (second molars to incisors) on articulator-mounted models is used to determine the MF. The MF is an articulator-defined reference plane reconstructed on the patient’s cephalometric radiograph. This plane allows the clinician to verify the accuracy of the articulator mounting. The dental vertical measurements from the longest central incisor and a second molar are chosen. The second molar, which is most easily identified on the cephalometric radiograph, is the most convenient to use. This procedure is demonstrated in Figures 7-12 through 7-15.

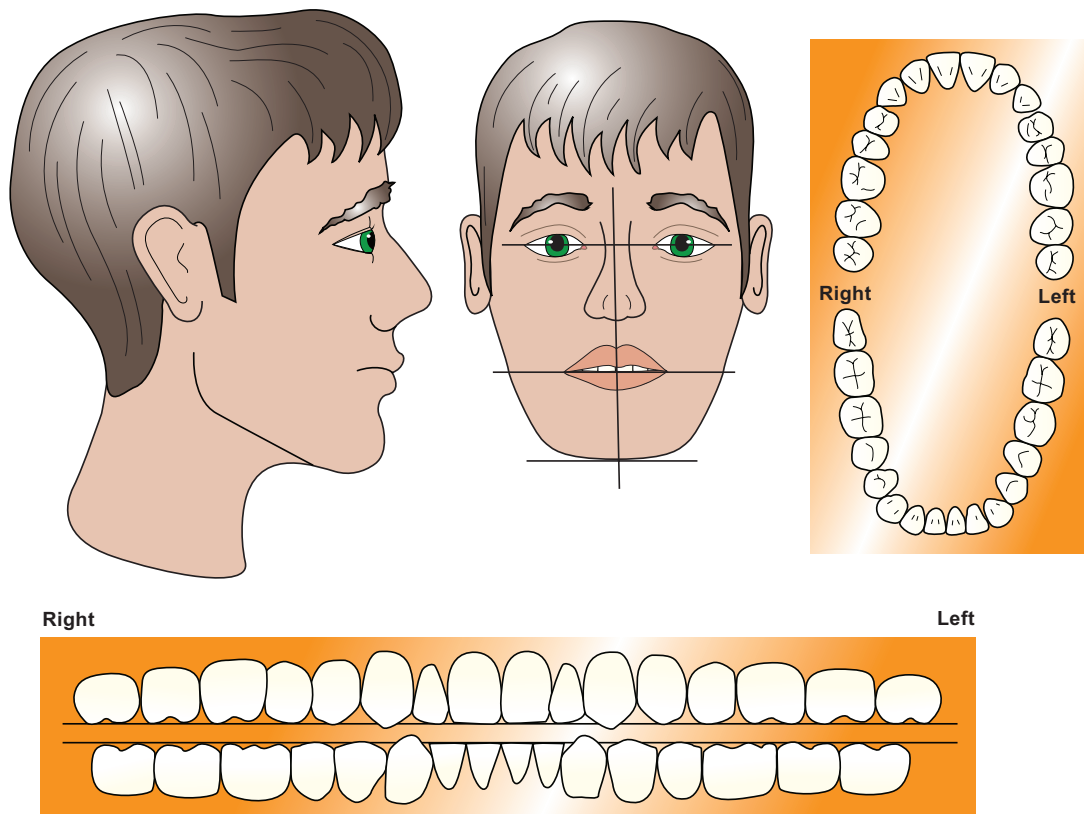


FIGURE 7-9 The model surgery record sheet. The sheet is used to record pre- and post-model surgery measurements.

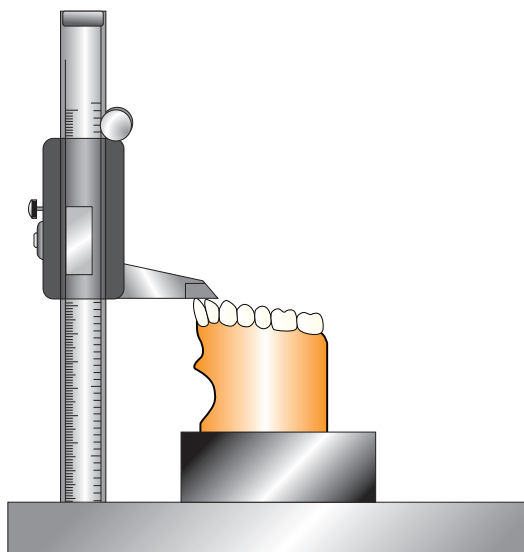


FIGURE 7-10 Dental vertical measurement of a maxillary incisor. The caliper contacts the incisal edge. Both incisors are measured and recorded.

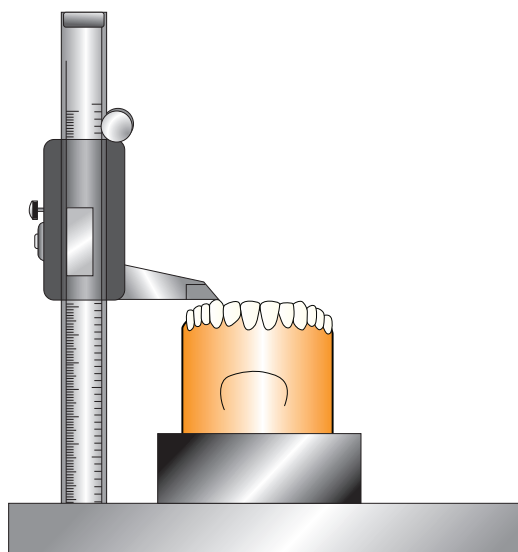


FIGURE 7-11 Dental vertical measurement of a maxillary cuspid. The caliper contacts the cuspid tip. Both cuspids are measured and recorded.

Bone Vertical Measurements (Maxilla)

Presurgical model measurements are of great clinical importance. During model surgery, the model will be repositioned in three planes of space according to the surgical prescription. Dental vertical, anteroposterior, and transverse measurements all contribute to positioning the maxilla in the appropriate spatial position. The net bone vertical calculations represent the final product of the three-dimensional change in space of the maxilla. These net changes measured at the level of the cut will serve as a “blueprint” for the surgery. The accuracy of these measurements, however, will be only as good as the accuracy of all of the previous steps; that is, mounting, the degree of anatomic trimming, correlation with radiographs, and cephalometric planning studies based upon a repeatable natural head position. Interpretation of the information generated from model surgery remains the responsibility of the surgeon.

In its most simple form, the lateral wall cut of a maxillary osteotomy is an essentially straight line extending from the piriform rim of the nose to the pterygomaxillary suture. For such procedures, the bone vertical measurement is a single circumferential reference line. The maxillary cast is first seated on the Model Block. The reference line will be scribed around the entire model at the level of the cut to simulate Le Fort I surgery. With the traditional Le Fort I osteotomy, this line is approximately 30 mm apical to the cuspid tip. The recorded measurement is made from the base of the Model Platform. The caliper must be “zeroed” at the platform base. The maxillary model is carefully spun around the caliper tip, making a perfectly parallel circumferential line on the model (Figure 7-16). Technically, this is a vertical reference line. Although the line is scribed in a horizontal plane, measurements of changes in the position of the line after model surgery will reflect *vertical* changes in bone at the Le Fort I level. Once the technique is understood, the surgeon can vary the points chosen for measurement to fit his/her needs.

Planning for Surgery: Additional Notes

Treatment planning of maxillary surgery is complex and must be individualized. The surgeon may wish to design the lateral maxillary wall cuts to facilitate a specific surgical movement. Traditionally, the anteroposterior orientation of maxillary osteotomies has been to incline the osteotomy from a high anterior position to an inferior posterior position.¹³ This design is based

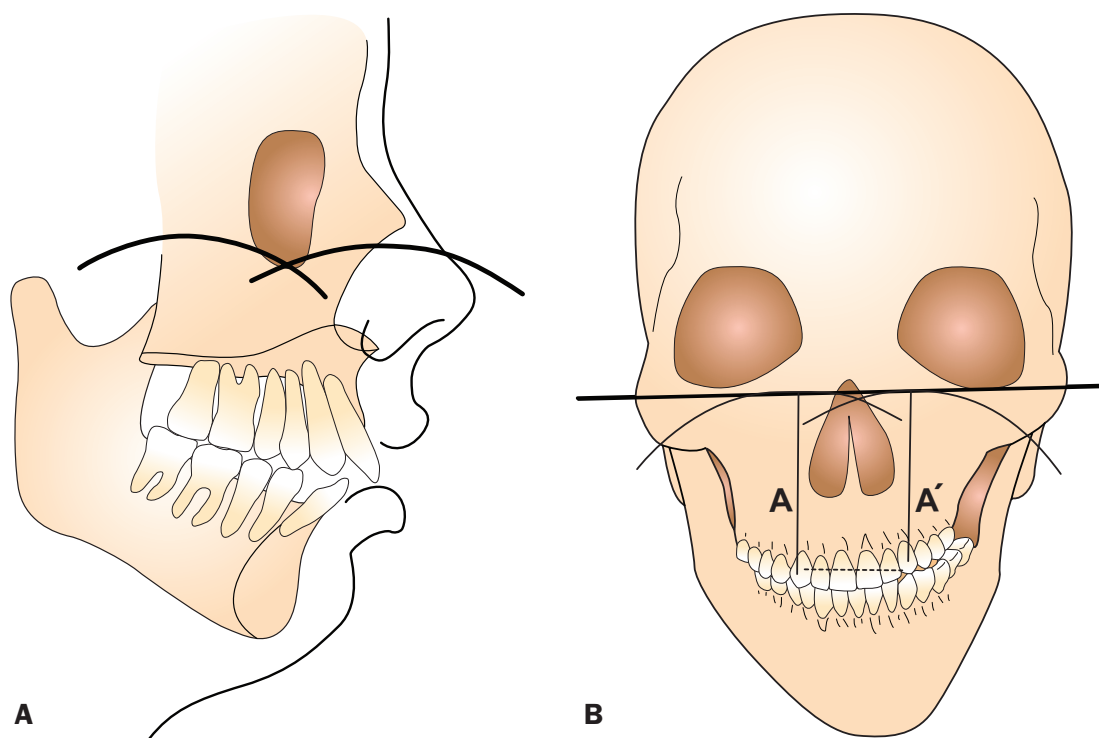


FIGURE 7-12 A and B A compass is used to scribe two arcs, one from the incisal edge of the central incisor and the other from a cusp tip from one of the second molars. The radius of each arc is equal to the vertical distance of the tooth (incisal edge or cusp) to the mounting ring. This distance is the dental vertical measurement of the tooth minus the thickness of the Model Block.

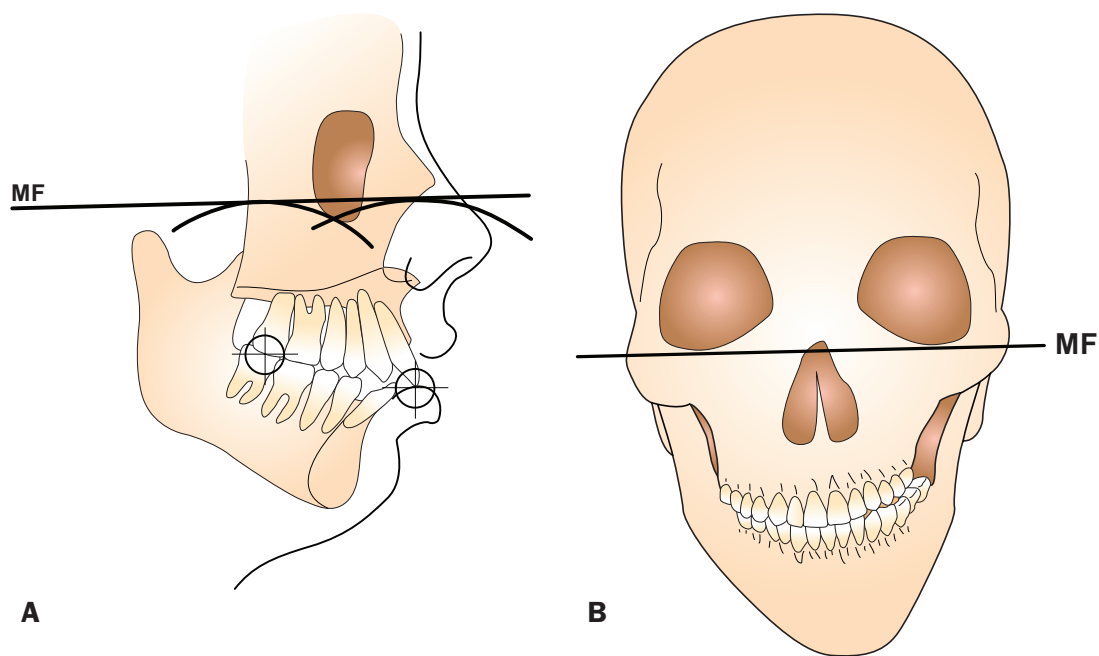


FIGURE 7-13 A and B A line tangent to the two arcs is then drawn. This line is the Model Frankfort (MF). The line is a “reconstruction” of the axis orbital plane (MF) on the cephalometric tracing. This technique allows the surgeon to confirm the accuracy of the articulator mounting. The same technique, using the right and left cuspids, can be carried out on a posteroanterior (PA) cephalometric radiograph.

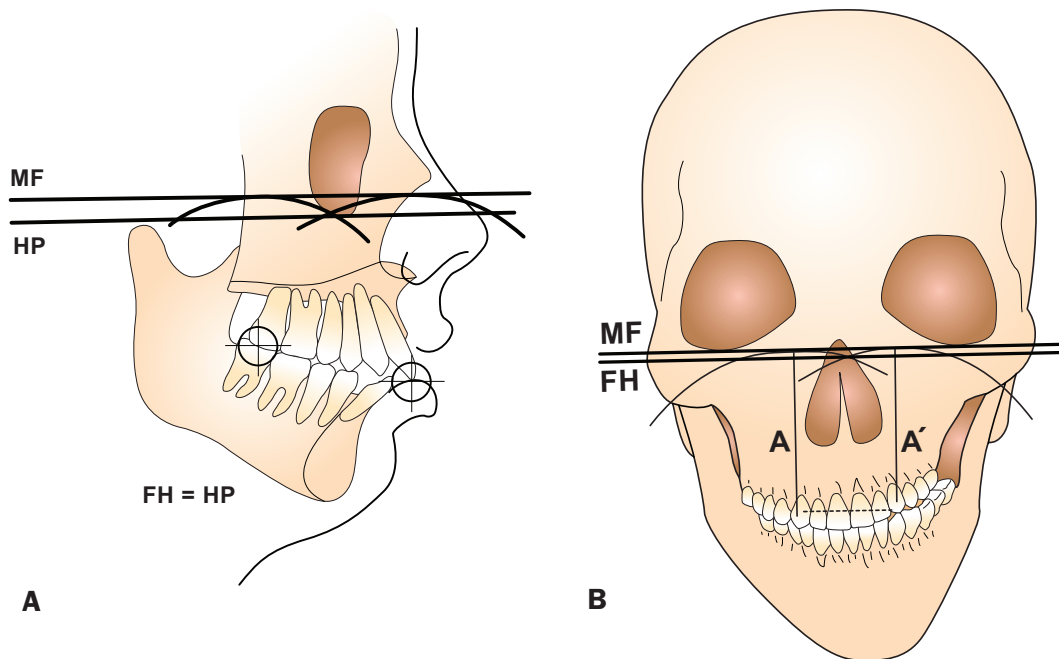


FIGURE 7-14 A and B When the Model Frankfort (MF) and Frankfort horizontal (FH) are parallel, the mounting is spatially accurate in a sagittal plane. As an example, the vertical movement of the maxillary incisor on the prediction tracing (as measured from the FH) will accurately correspond to the same vertical movement of the incisor on the mounted maxillary model (as measured from the MF).

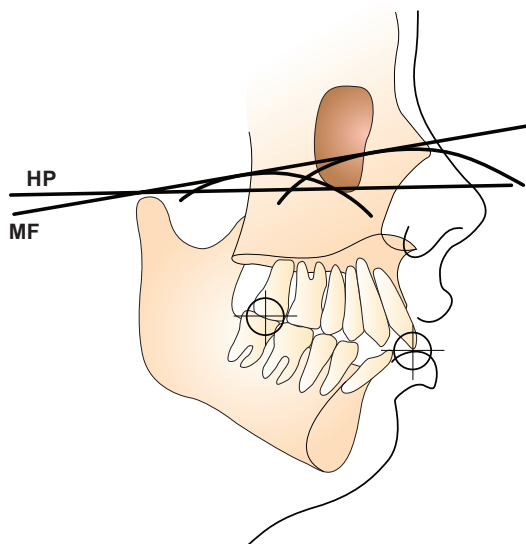


FIGURE 7-15 When the Model Frankfort (MF) and Frankfort horizontal (FH) are not parallel, the mounting is incorrect and may have to be repeated. In this case, the mounting (occlusal plane) is too steep. The vertical distance from the incisor to the MF (as measured perpendicular to the MF) is much greater than the distance from the incisor to the FH. A planned vertical movement of the maxillary incisor on the prediction tracing would not accurately correspond to the same vertical movement on the mounted model.

on the fact that the cuspid root is significantly longer than the molar roots. Since the posterior tooth apices are lower in relation to the cuspid apex, the osteotomy cut is inclined in a postero-anterior direction, creating a ramping effect. This anatomic ramp may positively or negatively

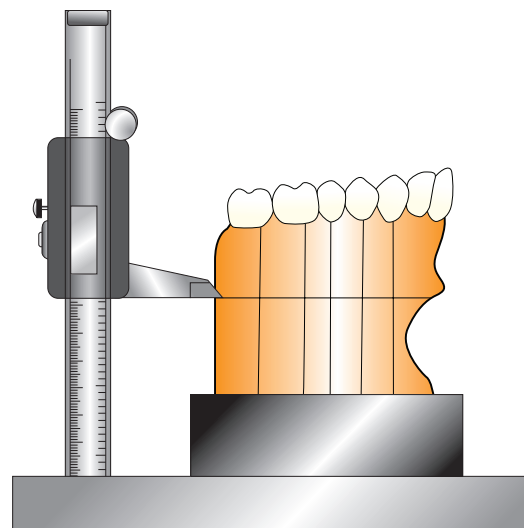


FIGURE 7-16 The model and Model Block are rotated on the Model Platform as the caliper tip is used to scribe a bone vertical reference line carefully around the entire cast. The reference line is placed at the level of the cut on the maxillary model.

influence the outcome of any procedure that changes the anteroposterior position of the maxilla. Compensation, individualization, and variation in the geometric design of the osteotomy in the lateral aspect of the maxilla, zygomatic buttresses, or roots of the zygoma are frequently necessary to avoid these problems and to achieve the esthetic and functional goals of orthognathic surgery.^{3,13}

When the angle of the ramp is designed to be parallel to the direction of the maxillary repositioning desired, movement of the maxilla parallels the plan created by the ramp. By controlling the ramp angulation and position, the surgeon can take advantage of the beneficial effects of the ramp when it is incorporated into the treatment plan. The key to achieving these objectives is proper planning through the correlative use of cephalometric planning and model surgery studies. Modification of the ramp angulation is limited by the osseous anatomy and tooth apices. With a traditionally inclined ramp, the maxilla moves forward and upward on the ramp as the maxilla is repositioned anteriorly. Since the entire maxilla is moving superiorly with the advancement, the mandible will reflect this movement with shortening of the lower facial third. If the maxilla alone is being advanced, the mandible must rotate superiorly and anteriorly. As a result of these combined movements, the maxilla must be repositioned farther forward than planned to achieve the desired occlusion. In selected cases requiring anterior maxillary repositioning that have a component of vertical maxillary excess, shortening of the lower facial third may be facilitated by planning to use the ramp. By advancing the maxilla along the ramp at an angle determined on the prediction tracing, surgical correction of excessive tooth-to-lip ratios may be achieved.

When the maxilla is moved posteriorly, it slides down the ramp. If this is not compensated for at the time of surgery, the mandibular movement will reflect this unplanned inferior positioning, with lengthening of the maxillomandibular complex. If single-jaw maxillary surgery is performed, the mandible must rotate in an inferoposterior direction, requiring the maxilla to move farther posteriorly than planned to achieve the desired occlusion. As a result, the entire facial complex is moved posteriorly, with concomitant facial lengthening. In selected cases involving marginal tooth-to-lip values, favorable results may be achieved by posteriorly repositioning the maxilla along the ramped osteotomy. Concomitant facial lengthening with posterior maxillary repositioning may then represent a desired component of the treatment plan designed to increase the incisor exposure a relatively small amount.

When anteroposterior maxillary deficiency is associated with vertical maxillary deficiency, the surgical plan may include maxillary advancement in addition to correction of the vertical discrepancy. In selected cases, both corrections may be achieved by downward and forward sliding movements of the maxilla. The osteotomy is angulated to provide an inclined plane that will increase the vertical dimension as the maxilla slides forward. Anteriorly, an angulated cut extends from high on the lateral aspect of the root of the zygoma to

low on the anterior piriform rim. Individualization of the lateral maxillary osteotomy design and the resulting movements may be simulated by meticulous analytic model surgery.

Lateral wall cuts may be designed with steps in the zygomatic buttress region or roots of the zygomas, with variations in the slope of the osteotomy cut. Variations in the slope and position of the surgical cuts can be simulated with model surgery procedures.^{3,13} The surgeon will be limited only by the dimensions of the articulator. Points and lines representing the planned osteotomy can be scribed on the sides of the model. The vertical measurements of these strategic marks are then made and recorded on a model surgery record sheet. The model is sectioned so that all model surgery marks remain on the lower (dental) mobilized portion of the cast.

**Bone Vertical Measurements
(Mandible)**

Mandibular Ramus Measurements

Ramus measurements are useful for quantifying distal segment movements in ramus procedures. Accurately estimating proximal segment movements with custom articulator accessories is possible but remains awkward for routine use. In model surgery for the sagittal split procedure, two points are chosen to represent the anterosuperior and anteroinferior limits of the proximal segment. The points are defined to 0.1 mm with the help of the Model Platform and Model Block in the vertical and anteroposterior planes (Figures 7-17 and 7-18). Reference lines scribed

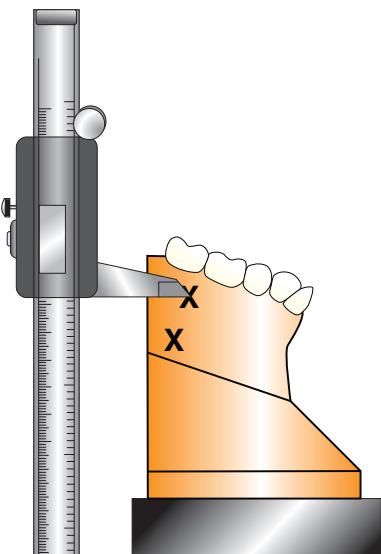


FIGURE 7-17 Representative bony points on the mandibular cast in the region of the ramus surgery are chosen and marked. Vertical and anteroposterior (see Figure 7-18) measurements of these points are made and recorded. These points will provide information on the movement of the distal mandibular segment.

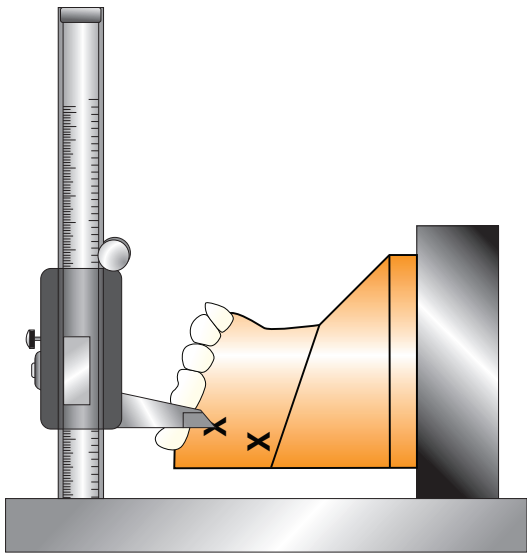


FIGURE 7-18 See legend for Figure 7-17.

on the posterior surface of the model (transverse reference lines) serve well for documenting transverse bone change. The measurements are recorded and compared with post-model surgery measurements.

Mandibular Chin Measurements

With limited anatomic trimming of the anterior mandible, a point can be scribed on the cast at the correct vertical, anteroposterior, and transverse positions and designed as the pogonion. Its position is measured and recorded before and after model surgery movements. Subtle changes in chin position may be due to alterations in occlusal plane, cant, and arch rotation. Changes in the occlusal plane cause changes in the anteroposterior projection of the chin. Alterations in cant and arch rotation produce transverse movements of the chin.

Mandibular Subapical Measurements

Mandibular subapical procedures are best treated as segments (see subsection, “Interdental Measurements,” above). Interdental osteotomies are measured with hand-held calipers after establishing reference marks (X’s) on the stone casts. Interdental measurements are made on either side of the subapical segment. Vertical changes in the subapical segment are handled in a similar manner. Reference marks are made at the appropriate level below the apices of the involved teeth on both ends of the segment. Additional marks, below the osteotomy site, are made on the portion of the cast representing the intact mandible. The distance required between the marks depends on the anticipated vertical change of the segment. Anatomic carving of the model significantly enhances the accuracy of the measurements.

Dental Anteroposterior Measurements

Like dental vertical measurements, these measurements are important for interrelating the model surgery with the prediction tracings. Anteroposterior dental measurements are limited to the incisal edges of the central incisors and the mesiobuccal line angles of the cuspids (Figures 7-19 and 7-20). The anteroposterior relationship of the cuspids and any net changes following model surgery will define arch rotation.

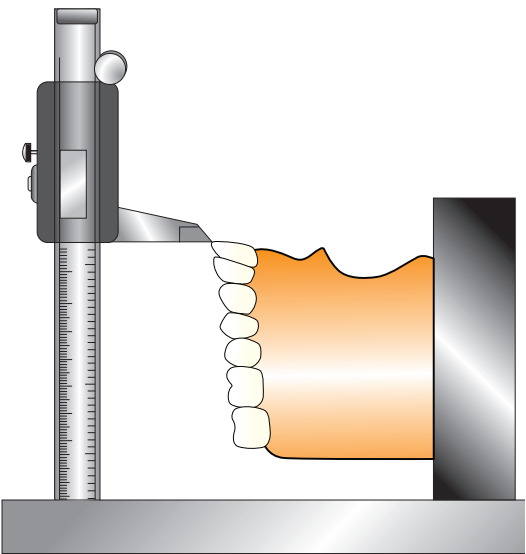


FIGURE 7-19 Dental anteroposterior measurement of a maxillary incisor. The caliper is placed at a reproducible point along the incisal edge. Both incisors are measured and recorded.

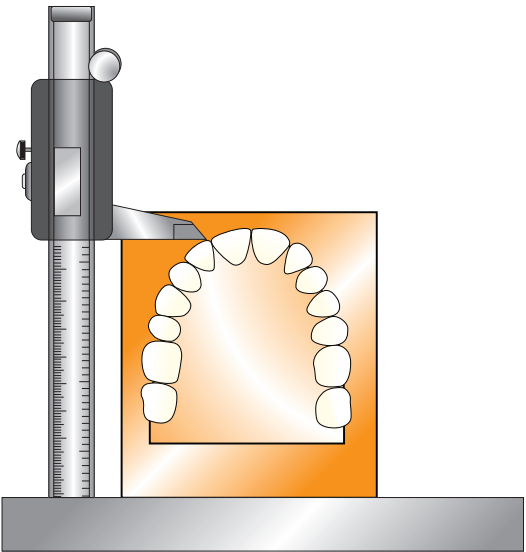


FIGURE 7-20 The Model Block is placed on its end to orient the model correctly for anteroposterior (AP) measurements. A dental AP measurement of the maxillary right cuspid is shown. The caliper tip is placed at a reproducible point on the mesial surface of the tooth. Both cuspids are measured and recorded.

Bone Anteroposterior Measurements

The surgical model is placed on the Model Block with the posterior surface of the block resting on the Model Platform. The caliper tip is used to scribe carefully a series of parallel lines that are perpendicular to the MF (Figure 7-21). These are spaced at the surgeon's discretion. One can place them at regular distances (eg, every 5 mm) or relate the reference lines to teeth (eg, one line for each tooth). It is not necessary to measure these lines. After surgical movement of the model, the surgeon can simply compare the anteroposterior distance of the "before" line with that of the "after" line at the level of the osteotomy. In the maxilla, this is extremely helpful in evaluating the need for bone grafting. If a graft is required, the surgeon will know the size and shape required. In the mandible, anteroposterior reference lines are helpful but will generally have less impact on treatment planning decisions. Two additional anteroposterior bone measurements are very useful. They are the measurement of A point in the maxilla and pogonion or chin of the mandible. Repositioning these bony landmarks has significant esthetic effects on overlying soft tissue. The A point and the piriform rim of the nose frequently advance more than the incisors in open-bite corrections. If the surgeon has this information, he/she may choose to reduce this bone at the time of surgery. Final chin surgery is planned on the prediction tracing after the body movement of the mandible (and therefore the pogonion) has been quantified. Accurate planning of chin surgery may be enhanced.

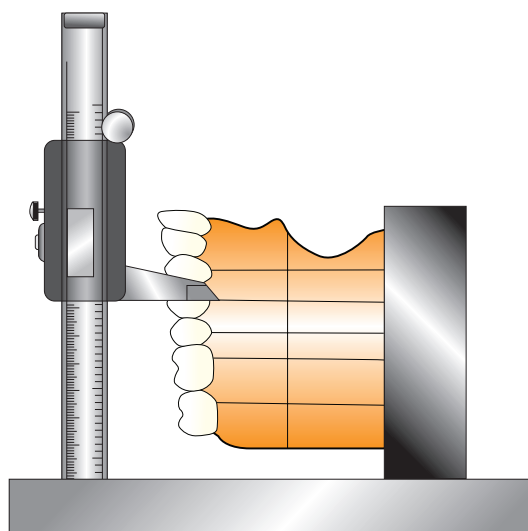


FIGURE 7-21 Anteroposterior (AP) reference lines are scribed on the model with the caliper tip. AP reference lines are perpendicular to the Model Frankfort.

Dental Transverse Measurements

For consistency, transverse dental and bone measurements should be made from the same side of the surgical models. The authors choose to make measurements from the right side of the model. The only dental transverse measurement generally recorded is the dental midline (Figure 7-22). In cases of complex multiple-segment maxillary surgery, the surgeon may choose to measure the first and last teeth in each segment.

Bone Transverse Measurements

Vertical reference lines (perpendicular to the MF) may be scribed on the posterior and anterior surfaces of the casts to reflect horizontal skeletal changes. These are conceptually similar to anteroposterior reference lines. The lines are scribed with the Model Block resting on its lateral surface. Typically, two parallel lines are scribed on the posterior of each model. These correspond to the right and left rami on the mandibular model and the right and left tuberosities on the maxillary model. A single line is scribed anteriorly, corresponding to the midline. It is not necessary to measure these lines. After surgical movement of the model, the surgeon can simply measure the difference between before and after lines and calculate transverse changes.

Cuspid-Nose Vertical Referent

A vertical referent procedure is an alternative method of measuring the correct vertical placement of the maxilla. Perhaps the simplest vertical referent is checking of the level of the incisor

compared with the upper lip at the time of surgery. Many experienced dentofacial surgeons use this method with very good results. Several different, more objective referent techniques exist.

The cuspid-nose vertical referent is different from other internal (intraoral) referent systems, as the measurements are initially made on the surgical models. A major advantage of anatomically trimming surgical models is the ability to employ a cuspid-nose referent. The referent measurement is based on changes in distance from two chosen points. It is best to make both right and left cuspid-nose referent marks. Theoretically, only one referent would be necessary. The temporomandibular joints, however, are not machined from inelastic materials, and there is some degree of play. Two referents allow for comparison.

A scalpel is used to mark an X on the cuspid at the approximate midportion of the orthodontic bracket. Another X is scribed on the anatomically carved model approximately 4 to 5 mm from the plaster lateral rim of the nose. The distance from the cuspid mark is dependent on the anticipated movement. If a 40 mm caliper is used at surgery, then the model surgery referent movements should not extend beyond this limit. For example, if the maxilla will be superiorly repositioned (the distance between the marks will decrease), then the marks should be placed so that the initial distance is near the upper limits of the caliper. If the maxilla will be downgrafted or advanced (the distance between the marks will increase), then the marks should be placed so that the final distance is no more than 40 mm, and therefore not exceeding the clinical limit of the caliper. When this method is used during model surgery, the net changes are recorded on the record sheet. The procedure is essentially duplicated at surgery on the patient (Figures 7-23 and 7-24). When carefully performed, the cuspid-nose referent is accurate and reliable.

Stanchina and colleagues advocate an external (extraoral) vertical referent system that has proved to be accurate and can be used independent of anatomic trimming of surgical models.¹⁴

More recently several investigators have compared the planned maxillary movements with the actual surgical movements. Their investigations have consistently found that extraoral vertical reference lines are more predictable than the traditional intraoral vertical referents. The results of these studies prompted us to develop an instrument to extraorally assess the vertical, anteroposterior, and horizontal positions of the maxillary incisors intraoperatively. Through the use of leveling devices, the spatial relationship of the maxilla is millimetrically related to the natural horizontal (HP) and the vertical reference plane (VP).

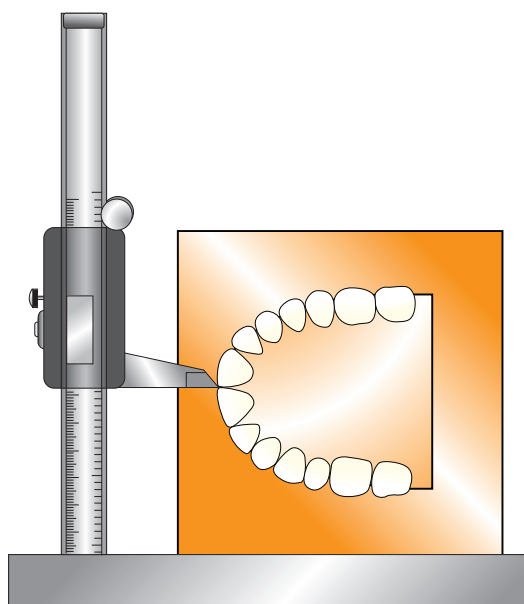


FIGURE 7-22 Transverse measurements are made with the model block on its side. The dental midline is measured and recorded. Pre- and post-model surgery measurements must be made from the same side. For consistency, the authors recommend that measurements are made from the right side.

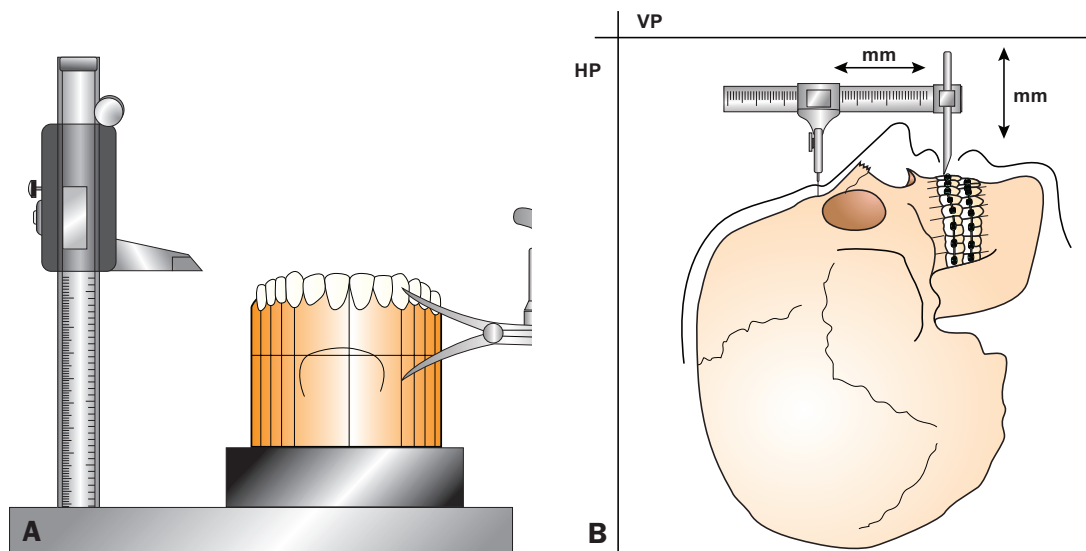


FIGURE 7-23 A, A caliper (Walter Lorenz Surgical Instruments Inc, Jacksonville, FL) is used to make a pre-model surgery cuspid-nose vertical referent measurement. The referent measurement is made independently of the Model Platform. This is an accurate referent system that is used as a model surgery procedure. When this referent system is used, it is necessary to carve the maxillary model anatomically in the nasal region. B, Prototype instrument designed to extraorally assess the vertical, anteroposterior, and horizontal position of the maxillary incisors intraoperatively. Designed by William H. Bell, Dallas, TX.

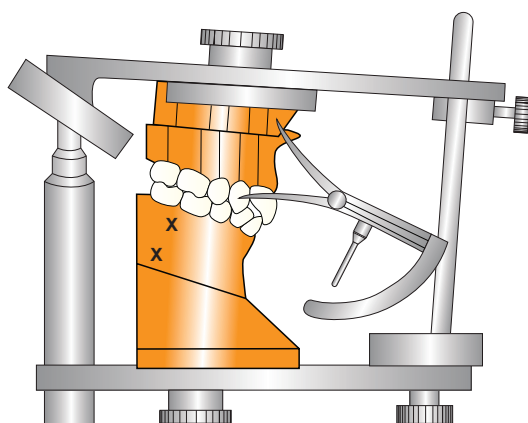


FIGURE 7-24 The post-model surgery cuspid-nose vertical referent measurement is made and recorded. The net change is calculated. Similar preosteotomy and postosteotomy measurements are made at the time of surgery. The surgeon uses the model surgery referent information to determine the correct vertical position of the maxilla during isolated maxillary and two-jaw surgery.

Points of Interest Common to All Treatment Schemes

Each treatment scheme lends itself to a systematic approach. A sample two-jaw model surgery case is presented. Model surgery techniques for isolated maxillary and mandibular surgery are also reviewed. Model surgery techniques for mandibular body procedures exist as part of this system but are not included in this chapter. A summary of the technical characteristics of each treatment scheme is included at the end of this section.

Full-sized anatomic articulators provide insight into the three-dimensional nature of surgical movements.

The authors advocate that a full-sized anatomic articulator be used for all model surgery procedures. With only a little practice, mounting procedures take minimal time and offer insightful spatial information. A reasonable argument, however, can be made for the use of a nonanatomic articulator in isolated mandibular surgery. In this type of surgery (Treatment Scheme I), the maxilla acts as a stable template for the mandible. Accurate mounting of the surgical models will not affect the final position of the distal segment of the mandible. Optimal positioning of the proximal mandibular segments continues to depend on the surgeon's skill and experience. A full-sized anatomic articulator, however, does offer some advantages over a nonanatomic articulator. With an anatomic articulator, the surgeon is better able to understand the three-dimensional nature of mandibular movement and therefore anticipate both esthetic and positioning problems. More information concerning the transverse movements of the mandibular angles and the final anteroposterior position of the chin will be available.

Anatomic likeness or reproduction of the surgical models will always improve the information gained from model surgery.

The surgeon is able to obtain valuable information from the model surgery osteotomy sites when bone measurements are made. Casts that are *anatomically carved* will provide the best information. Anatomic sculpting of surgical models will allow the surgeon

to obtain information such as anteroposterior changes at the A point in maxillary surgery or the chin in mandibular surgery. Anatomic carving of the base and lower lateral portions of the nose for maxillary surgery will allow the surgeon to use an internal vertical referent with improved accuracy. When an external vertical referent is used, such as that advocated by Stanchina and colleagues, the value of anatomic carving will be reduced.¹⁴ In all cases, however, anatomic carving will help the surgeon better understand the complexity of a surgical movement and final bone contact.

Reconstructing the MF on the cephalometric radiograph will always be helpful in ensuring that the mounted models and radiograph are oriented to a common reference plane.

To reconstruct the MF on the radiograph or tracing, the following steps must be performed (see Figures 7-12 to 7-15):

1. On the maxillary cast, dental vertical measurements of the longest central incisor and the lingual or distobuccal cusp of a second molar are recorded. The second molar, which is most easily identified on the cephalometric radiograph, is the most convenient to use.
2. With a compass, arcs are drawn from the chosen second molar cusp tip and the central incisor on the tracing. The radius of each arc equals the dental vertical height as measured on the Model Platform (see Figure 7-12).
3. On the tracing, a line is drawn that is tangent to the arc of the central incisor and the arc of the second molar. This line represents the MF (see Figure 7-13).
4. If the models are correctly oriented, the MF should be parallel to the patient's FH (see Figure 7-14). If the mounting is significantly different (MF greater than 5° higher or lower than the FH), then the clinician may consider repeating the face-bow transfer and remounting the case (see Figure 7-15). The closer the mounting is to the patient's facial structure, the more closely the final model surgery will represent the patient's surgery.

Reconstructing the MF on the cephalometric radiograph or tracing allows the surgeon to verify the mounting. The same procedure can be performed on a posteroanterior film. This procedure is very helpful in assuring the correctness of articulator mountings in cases of asymmetry.

Interdental osteotomies (segments and subapical procedures) are treated independently of whole-jaw movements.

When segments are performed during model surgery, it is important to complete them prior to performing whole-jaw movements. Segmental surgery is measured (in horizontal and vertical planes) with a hand-held Boley gauge

or Beerendonk caliper. When segments are performed in both the upper and the lower models, the mandibular arch is always established before the maxillary arch. As an example, the following complex surgical case may be considered: a patient requiring an anterior mandibular subapical osteotomy, a mandibular advancement, and a multiple-segment Le Fort I maxillary osteotomy. In this case, the mandibular subapical procedure (measured as interdental osteotomies) would be performed first to level the mandibular arch. The maxillary dentoalveolar segments are then positioned on the mandibular arch (template) according to sound occlusal principles.¹⁵ The maxillary segments are unified into a whole arch with wax. With each arch established, they are now treated as whole-jaw segments.

Model surgery worksheets are used to record before and after model surgery measurements. Although all of the measurements could be placed on one sheet, the authors use several. In general, one sheet is used for dental vertical measurements, and a second is used for bone vertical measurements. Anteroposterior dental and bone measurements are placed on the same sheet as for transverse dental and bone measurements. A final sheet is used for interdental osteotomy measurements.

Technical Summary

Treatment Scheme I: Functionally Isolated Mandibular Surgery

Articulator. A full-sized anatomic articulator is recommended by the authors, especially if mandibular or maxillary segmental surgery is performed in combination with ramus surgery. Successful surgical planning can be done with nonanatomic articulators in combination with prediction tracings.

Incisal pin. The incisal pin will be set so that the upper and lower members of the articulator are parallel or nearly parallel. No autorotation of the models will occur during model surgery procedures. The pin will remain unchanged throughout the model surgery procedures.

Models. One upper model and one lower working model are needed. Additional models may be required for feasibility model surgery.

Necessary treatment decisions. In choosing this treatment scheme, the surgeon has accepted the maxilla as a template.

Treatment Scheme II: Functionally Isolated Maxillary Surgery

Articulator. A full-sized anatomic articulator is recommended by the authors. It is required to autorotate the maxillary cast accurately into position. The mandible rotates superiorly and

inferiorly around the intercondylar axis (hinge axis) of the articulator. Accurate face-bow transfer techniques and centric-relation bite techniques ensure that the models are correctly mounted and that a properly simulated hinge-axis rotation is produced.

Incisal pin. The models are mounted so that the upper and lower members of the articulator are parallel or nearly parallel. The incisal pin will be released and will change with autorotation of the lower member of the articulator during model surgery procedures. When the maxilla is raised, the pin will shorten (the distance between the upper and lower members of the articulator will decrease). When the maxilla is lowered, the pin will lengthen (the distance between the upper and lower members of the articulator will increase).

Models. One upper model and one lower working model are needed. Additional models may be required for feasibility model surgery.

Necessary treatment decisions. The surgeon must choose *vertical* placement of the anterior maxilla (tooth-to-lip determination).

Treatment Scheme III: Two-Jaw Surgery

Articulator. A full-sized anatomic articulator is recommended by the authors. It is required to register accurately the new position of the operated-upon maxilla relative to the unoperated-upon mandibular model during construction of the intermediate splint. Accurate face-bow transfer techniques and centric-relation bite techniques ensure that the models are correctly mounted and that a properly simulated hinge-axis rotation is produced.

Incisal pin. The models are mounted so that the upper and lower members of the articulator are parallel or nearly parallel. The incisal pin is set, and its position is recorded. The pin will remain unchanged during maxillary and mandibular model surgery and primary (surgical) splint construction. A second mandibular model (unoperated) is used for intermediate splint construction. The incisal pin will be released and will change with autorotation of the lower member of the articulator during intermediate splint construction. The final vertical position of the maxilla and the overall thickness of the surgical and intermediate splints will determine the final incisal pin setting. The intermediate splint will accurately register the position of the operated-upon maxillary model relative to the unoperated-upon mandibular model. The intermediate splint should be constructed with the articulator changed as little as possible from its original position. This is not always possible.

In general, the intermediate splint should be as thin as possible while still strong enough to perform in a reliable manner.

Models. One upper model and two lower working models are needed. Additional models may be required for feasibility model surgery.

Necessary treatment decisions. The surgeon should choose the following:

- *Vertical* placement of the anterior maxilla (tooth-to-lip determination)
- *Vertical* placement of the posterior maxilla (vertical change of the second molars)
- *Vertical* changes of the right and left sides of the maxilla (maxillary cant, best measured at the cuspids)
- *Anteroposterior* position of the maxilla (anteroposterior change of the maxillary incisor)
- *Anteroposterior* changes of the right and left sides of the maxillary arch (arch rotation, best measured at the cuspids)
- *Transverse* placement of the midline of the maxilla (dental midline)

The Road Ahead

Model surgery is an important and critical part of surgical planning. These procedures allow and even compel the surgeon to systematically analyze the patient in three planes of space. It is common that the treating surgeon will modify or “tweak” the final surgical plan during the model surgery procedures. The three-dimensional model movements on the trial casts may alert the surgeon to potential difficulties or even opportunities related to the patient’s surgical plan.

Treatment of jaw growth deformities continues to evolve. Distraction osteogenesis procedures do not eliminate the need for planning, but rather offer a new role for model surgery in the planning process. In cases of both maxillary and mandibular distraction, the author (Kim Erickson) has used a SAM MVP (Mandibular Position Variator, Great Lakes Orthodontic Products, Ltd) articulator to calculate A–P and vertical movements of the maxilla or mandible. This particular articulator will not only greatly help in accurate calculation of surgical movements (within the physical range of the articulator) but will also allow conventional and “dynamic” splint construction.

A conventional surgical splint can be constructed prior to surgery and placed in the mouth after the distraction movement has been completed. Such a splint can be very useful in the consolidation phase following distraction. A “distraction osteogenesis splint” (DOS) or “dynamic” splint can be constructed with the use of the SAM MVP articulator. The planned surgical movement

is carried out on the articulator, over a period of minutes while the cold cure acrylic is setting. When done carefully, this results in a “smart” splint with troughs in the acrylic that can guide jaw movement to the final planned end point. As these techniques evolve and become more standard, distraction procedures will become more predictable and more common.

Table 7-1 of this chapter lists the primary and secondary components of the presurgical information (database) required for patient evaluation and treatment planning. Planning has not undergone dramatic change over the last few years. To date, model surgery procedures have largely remained a plaster and sticky-wax exercise. The plaster model is a highly accurate facsimile of the patient’s real maxilla or mandible. Accurately mounted models on modern articulators have allowed surgeons to plan and carry out trial surgery with a high degree of predictability. This is about to change.

In the near future, patients with dentofacial deformity will be sent for computed tomography scans, and three-dimensional surgical planning will take place on laptops. Surgical planning will be accomplished in minutes rather than hours. The surgeon will still be in charge and responsible for the process. The patient’s three-dimensional digital image will be manipulated on the computer screen. The surgeon will closely view the movements of the osteotomized segments and the bony relationships at the osteotomy sites. The amount of bone to be removed or added will be automatically calculated and, when finished, tabulated. Condylar position will be evaluated. A “skin” function will allow the surgeon to evaluate the soft tissue consequences of the bony movement. The trial monitor (model) surgery will be “tweaked” as before. The trial surgery result will be “saved” and perhaps reviewed the following day or week. When an optimal plan has been achieved, the surgical data will be sent over the internet to a specialized laboratory and a surgical Splint constructed. For both patients and surgeons, the future is bright and exciting.

Case Study

A 20-year-old female was initially seen for treatment of her complex three-dimensional facial asymmetry. She experienced mandibular dysfunction, pain and episodic locking of her temporomandibular joints. A retrospective study of previous sequential treatment records revealed that her problem had become increasingly manifest clinically over a period of 8 to 9 years (ages 7-16). There was no discernible asymmetry at age 7 (Figure 7-25) Clinical examination revealed the following additional information:

Esthetic Analysis

The patient’s face was asymmetric and disproportionate in all three planes of space. The maxillary



FIGURE 7-25 Age 7, no discernible facial asymmetry.

and mandibular occlusal planes were canted (Figure 7-26A). The right side of her face was flattened and longer than the left side; the right orbit relatively lower than the left orbit (Figure 7-26B and C). Additionally, the chin was 3-dimensionally asymmetric, deviated 3 mm to the left of the mandibular dental midline and 5 mm to the left of the facial midline. The upper lip line and occlusal plane were tilted upward toward the left. She manifested lip incompetence, asymmetric excessive exposure of the maxillary right teeth and gingiva in repose and when smiling (Figure 7-26D). The maxillary dental midline was deviated 3 mm to the right of the facial midline. She showed mild anterior-posterior maxillary deficiency because the mandible had undergone disproportionate sagittal growth. Radiographic analysis revealed that facial asymmetry was secondary to right unilateral condylar hyperplasia with shifting of the maxilla and mandible to the contralateral left side (Figure 7-27A). The right mandibular condyle was approximately 11 mm longer than the left condyle. (Fig. 7-27B) and associated with disproportional facial height (right side of face 11 mm longer than left). The mandible was displaced to the left by the disproportionate right condylar growth.

Occlusal Analysis.

The maxillary and mandibular dental arches were 3-dimensionally asymmetric. The midline of

the mandibular incisors was positioned 3 mm to the left of the maxillary incisors. A lateral class III molar and canine relationship was associated with a right palatal and left buccal cross bite (Figure 7-28 A–C). Horizontal maxillary deficiency was manifest when study models were hand articulated into a simulated Class I molar and canine relationship.

Surgical Treatment Plan

Asymmetric maxillary deficiency and asymmetric mandibular excess were corrected by three-piece Le Fort I osteotomy, bilateral intraoral vertical ramus osteotomies and transverse sliding genioplasty. There was a typical discrepancy between dental, skeletal, genial, and facial midlines. The plan of surgery consisted of Le Fort I osteotomy to level the maxillary occlusal plane, rotate the maxilla to the facial midline, widen the maxilla 5 mm, differentially raise the right maxilla to decrease tooth and gingival exposure and interlabial gap, and achieve a symmetric smile. Bilateral intraoral vertical ramus osteotomies achieved three-dimensional maxillo-mandibular harmony and rotated the mandible to correct the dental midline and achieved Class I canine and molar relationship. Lateral augmentation of the long and flat side of the face was achieved by stabilizing the chin segment lateral to the labial cortex of the superior segment and advancing the segment more than the contralateral side. Surgical procedures corrected the discrepancy between the maxillary and mandibular skeletal, dental, genial, and facial midlines (Figure 7-29 through 7-31).

Follow-Up

This case illustrates how a good functional occlusion with normal facial proportions was achieved for a patient with complex facial asymmetry by numerous three-dimensional changes of the maxilla, mandible, and chin in combination with orthodontics within a period of 17 months. An orthodontic diagnostic set-up, model surgery, and cephalometric planning studies of the posterior-anterior and lateral head radiographs indicated the feasibility of the surgical plan. A three-dimensional assessment of the maxillary spatial relationships and planned changes was made by model surgery of dental casts mounted on an anatomic articulator coordinated with cephalometric planning studies. The posterior changes were calculated by a careful correlation of the positional changes of the sectioned models with clinical study of the upper lip-to-tooth relationships and posterior smile line. The anterior positional changes were determined exclusively from a study of the right and left upper lip-to-tooth relationship with the lips in repose and during animation. All three planes of space were considered when the asymmetric jaws and chin



FIGURE 7-26 At age 18, five years after orthodontic treatment was started, three-dimensional facial asymmetry and vertical disproportion manifest preoperatively. The maxillary and mandibular occlusal planes were canted (A). The right side of the patient's face is flattened and longer than the left side (B and C). There was excessive posterior maxillary gingival exposure when smiling (D).

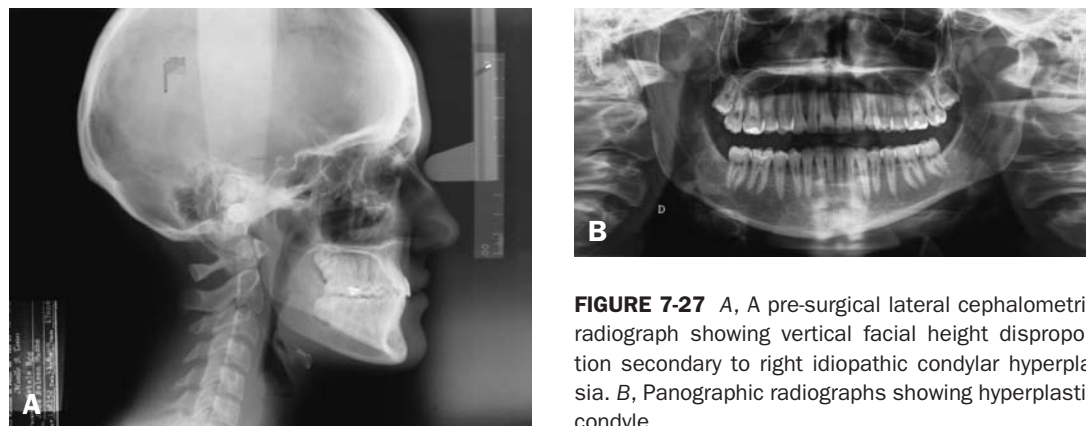


FIGURE 7-27 A, A pre-surgical lateral cephalometric radiograph showing vertical facial height disproportion secondary to right idiopathic condylar hyperplasia. B, Panoramic radiographs showing hyperplastic condyle.

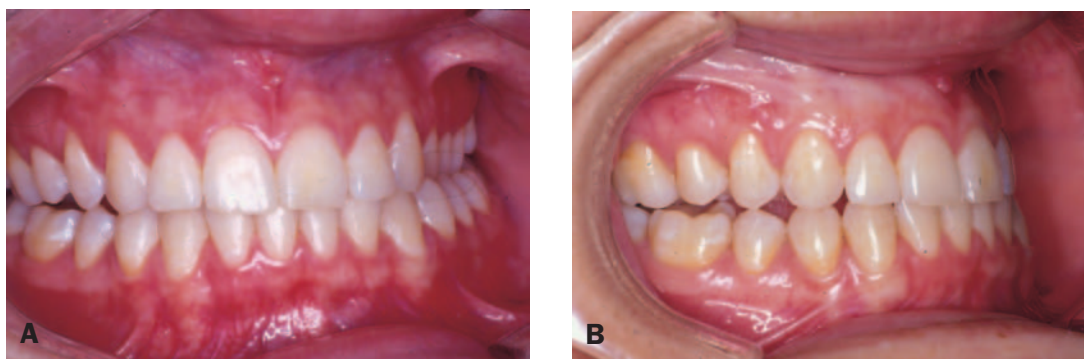


FIGURE 7-28 A and B, Asymmetric Class III occlusion.



FIGURE 7-29 Postoperative cephalometric radiograph showing facial proportionality

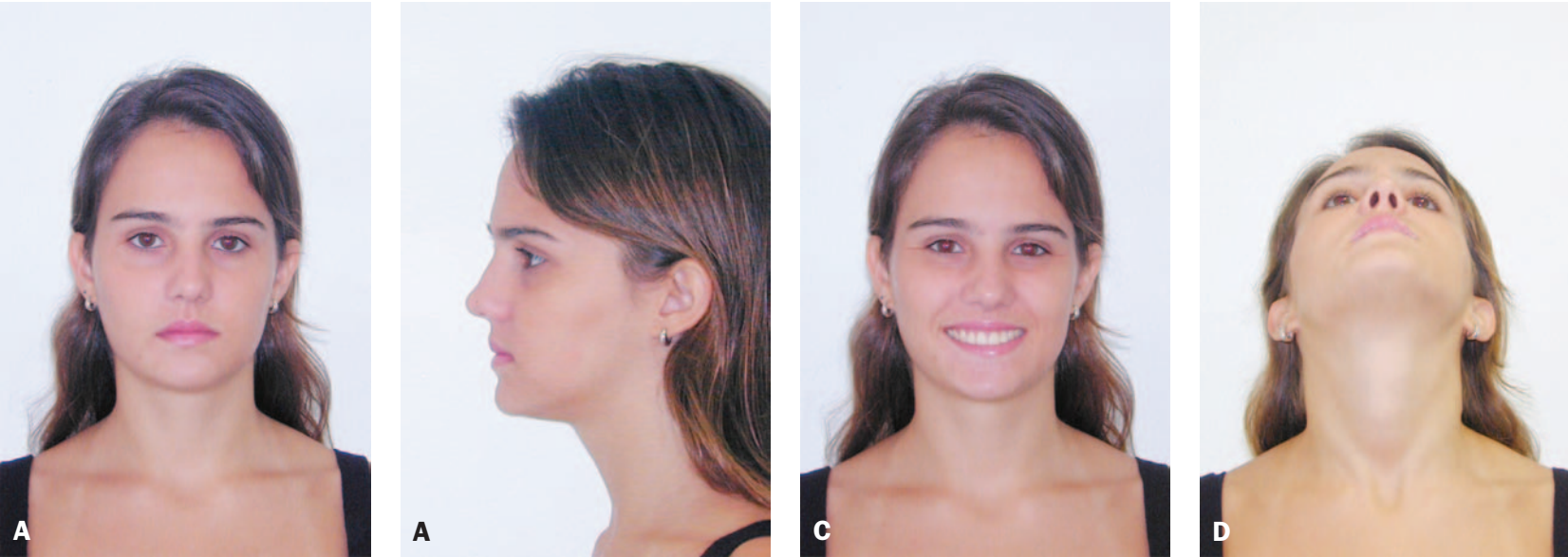


FIGURE 7-30 A to D, Postoperative facial views showing facial proportion and symmetry obtained by surgical treatment.

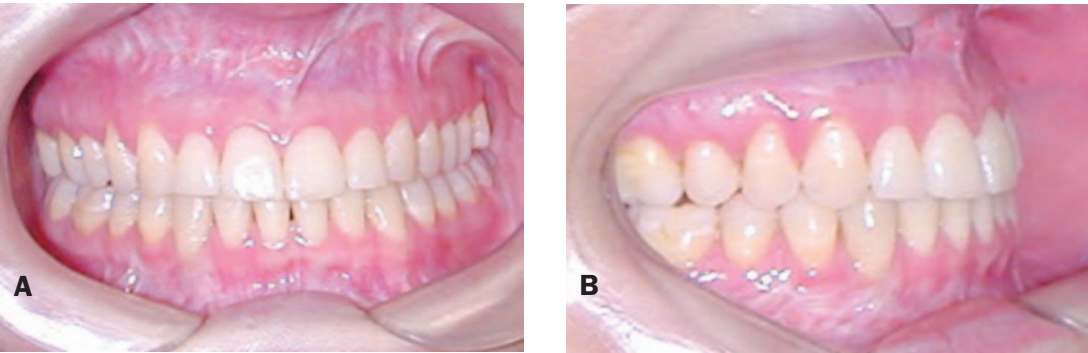


FIGURE 7-31 A and B, Class I occlusion two years after orthognathic surgery

were repositioned to achieve maxillomandibular harmony.

A number of relatively small three-dimensional complex positional movements of the maxilla and mandible mandated meticulous anatomic model surgery. Since the time of surgery the patient has been free of temporomandibular joint dysfunction, pain and episodic locking of her temporomandibular joints.

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Tactile Surgical Planning Using Patient-Specific Anatomic Models

Andrew M. Christensen

Accurate surgical planning requires knowledge of not only the surgical procedure but the patient's unique anatomy as well. Adaptation of a procedure, osteotomy, or device to distorted anatomy is one of the major challenges of reconstructive surgery. Tactile models produced from the computed tomography (CT) or magnetic resonance imaging (MRI) scan of an individual patient's anatomy aid in precise surgical planning. Accurate, custom-made, anatomic replica models produced from medical imaging studies have found increasing use in reconstructive surgeries. Their use is easily seen in preparation for surgery through advanced planning and diagnostic work-up, although increasingly the models are also employed during the procedure (Figure 8-1A). Reported literature has shown that the use of physical models of the bone structure in planning for and executing surgical interventions reduced

operating time by an average of 20%.¹⁻³ This time-savings results from more thorough planning, made possible by the use of life-sized individual plastic models created from medical imaging studies. Reported benefits of using these models for surgical planning include (1) enhanced visualization of the anatomic structures involved, (2) the ability to simulate surgery on the model preoperatively, (3) the ability to create fully customized devices for severe cases that will not accommodate off-the-shelf devices, (4) enhanced communication with other surgeons and staff who will be involved in the treatment of the patient, and (5) better communication with the patient about exactly what will be done during surgery.

In traditional case planning, the surgeon must rely on standard radiographs, including a panoramic radiograph, lateral cephalometric

radiographs, and two-dimensional (2D) CT scans. These tools, although providing immensely more information than was available before their advent, only provide at best a limited three-dimensional (3D) view into the patient's condition or deformity. Lack of true 3D information can lead to improper diagnosis or the choice of an improper surgical procedure for correction of the patient's condition. Increasingly common is the use of 3D CT scans, which are produced by stacking the 2D CT slices into a 3D volume. Whereas again more useful than their 2D counterparts, 2D CT is still displayed in a 2D manner; that is, on printed film or the computer screen, and as such requires interpretation for correct use. Even 3D CT cannot provide a tactile feel for the deformity, or a true sense of scale. Three-dimensional replica models are the only imaging technology combining the very

A



FIGURE 8-1 A, Two-color stereolithography models in use for planning and as reference during the surgical procedure. Certain photopolymer resin materials can be sterilized and taken into the sterile field during surgery for reference. At times, these models are used as templates to allow for autogenous bone graft fitting during the procedure.

important aspect of scale (ie, ability to visualize in true 1:1 ratio) and usability for “hands-on” case planning. Hands-on case planning refers to the ability of the surgeon to use the model for simulating osteotomies, prebending rigid fixation, and deciding on appropriate sizing of instruments or devices prior to the case.

As CT scanning techniques became clinically viable in the 1970s, surgeons had the first glimpse at a set of spatially correct data produced noninvasively.⁴ This revolutionized the diagnosis and treatment of many different pathologies and has continued to expand its scope ever since. Immediately, some saw the ability to create 3D CT images by stacking the bone structures from each slice on top of each other. This technique allowed for visualization in 3D, which surgeons had never seen before, and allowed for visualizing anatomic deformities and traumatic injuries in a more straightforward manner. Since the mid 1980s, several technologies have been available for fabrication of 3D physical models using medical image data such as CT scanning.^{5,6} Companies and clinical research groups have produced these models for several years using milling techniques with materials such as foam and polyurethane.⁷ Milling is classified as a subtractive process, because material is removed to form the object. Although this technique can ultimately provide a fairly precise model of a 3D structure, it lacks the ability to provide accurate internal and external structures for assessment of the pathology presented. The advent of a group of machinery now referred to as “rapid prototyping” or “additive fabrication” started with the invention of the stereolithography (SLA) process in the late 1980s.⁸ This technique uses a laser-curing polymer process, which provides product designers with a glimpse into the provision of models that are extremely accurate. Owing to their transparency, they also allow for visualization of internal structures such as nerve canals and sinus cavities. In planning reconstructive surgical procedures using either traditional surgery or distraction osteogenesis, the ability to see the quantity, thickness, and position of bone segments is crucial, and scale models of the anatomy facilitate this planning. Many commercially available processes now exist within the scope of rapid prototyping. These processes differ by output modeling material, method of model construction, and variables such as production time and postprocessing time. The most popular processes within the rapid prototyping field are SLA, selective laser sintering (SLS), 3D printing (3DP), fused deposition modeling (FDM), and multi-jet modeling (MJM) (Figure 8-1B).⁹

Anatomic models of the hard tissue anatomy are typically produced to aid planning for reconstruction of osseous defects or deficiencies. The appropriate imaging modality for acquiring this

B



FIGURE 8-1 B, Examples of anatomic models produced using three-dimensional printing (*opaque white model*) and two-color stereolithography (*clear with red coloration*) techniques. Coloration of vascular structures can be accomplished using either a computed tomography (CT) angiography study or combination of magnetic resonance imaging and CT data.

data is CT scanning. It is interesting to note that CT can also be used for creation of soft tissue models, most specifically of the external anatomy. If inclusion of tumor or vascular structures is required for modeling, a CT scan with intravenous contrast is performed, allowing for visualization and segmentation of lesions or vessels in addition to the bony anatomy. A two-color SLA modeling process is now available, which allows for segmentation of a separate structure apart from the bone. This unique approach can also be used effectively for identification of the inferior alveolar nerve structures, tooth structures, and soft and hard tissue tumors, as well as existing implants.¹⁰ The selective coloration process relies on overcuring of select areas of a 2D layer, resulting in a color change within the material, changing from clear to red. Another advantage of this process is that the material has been tested against United States Pharmacopeia (USP) Class VI biocompatibility testing, allowing for limited in vivo exposure to human tissues. This enables the model to be sterilized for use as a reference tool in the operating room. This becomes an important issue when using the model for reference during surgery or for intraoperative preparation of grafts or resorbable polymers for use during surgery.

Models can be easily obtained by ordering through companies that specialize in the production of models, called service bureaus. A competent service bureau will employ radiologic staff who are trained in the issues surrounding the imaging of the human body and can make informed decisions about the production of these highly accurate models. Because the machinery is very expensive to purchase and maintain, hospitals and medical centers by and large are not

able to bring this technology in-house. The process of obtaining a model involves transfer of the data from the CT scan to the modeling facility and lead time of 3 to 7 days for model production. Increasingly, this can be done over the Internet with digital imaging and communications in medicine (DICOM, NEMA, Rosslyn, VA; accessible at: <http://medical.nema.org>) image transfer protocol or file transfer protocol (FTP) directly from the radiology center (Figure 8-1C).

Medical Imaging for Anatomic Modeling

Medical imaging for anatomic modeling of osseous structures typically relies on use of CT scans. Computed tomography scans are optimal for imaging structures such as bone, air-containing sinuses, and the external contour of the face. (Figure 8-2A) CT, although providing near-optimal images, involves very expensive equipment and fairly high doses of radiation. Reducing radiation dosage and capital equipment cost have led to the commercialization of a new class of imaging technology, referred to as cone-beam computed tomography (CBCT, also called cone-beam volume tomography), to become adopted within dental specialties. CBCT offers the possibility to acquire faster 3D data sets at high spatial resolution and with reduced amounts of radiation exposure to the patient. Combine these benefits with a capital cost that is a fraction of that of a regular CT, and one can see the potential for this technology to be adopted for in-office scanning. Many surgeons currently have access to CT-like images, taken very quickly right in their office and without large doses of radiation.

C

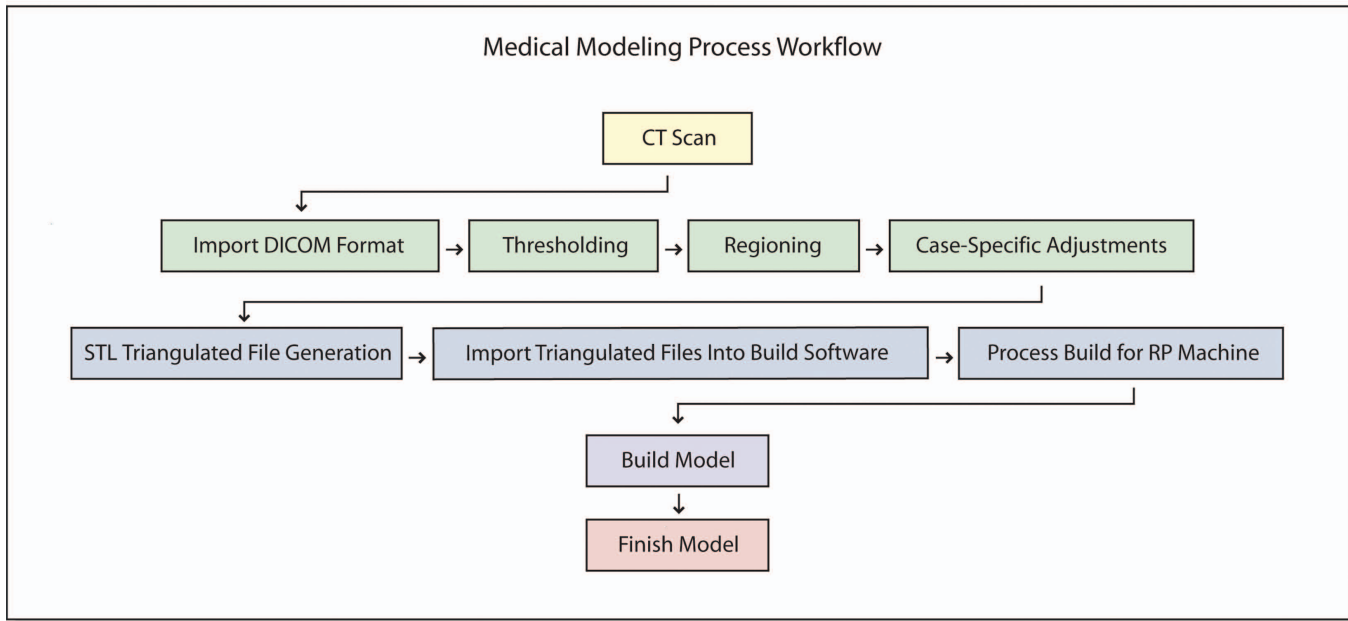


FIGURE 8-1 C, Flowchart showing typical workflow for production of an anatomic model from computed tomography scan to finished model.

A

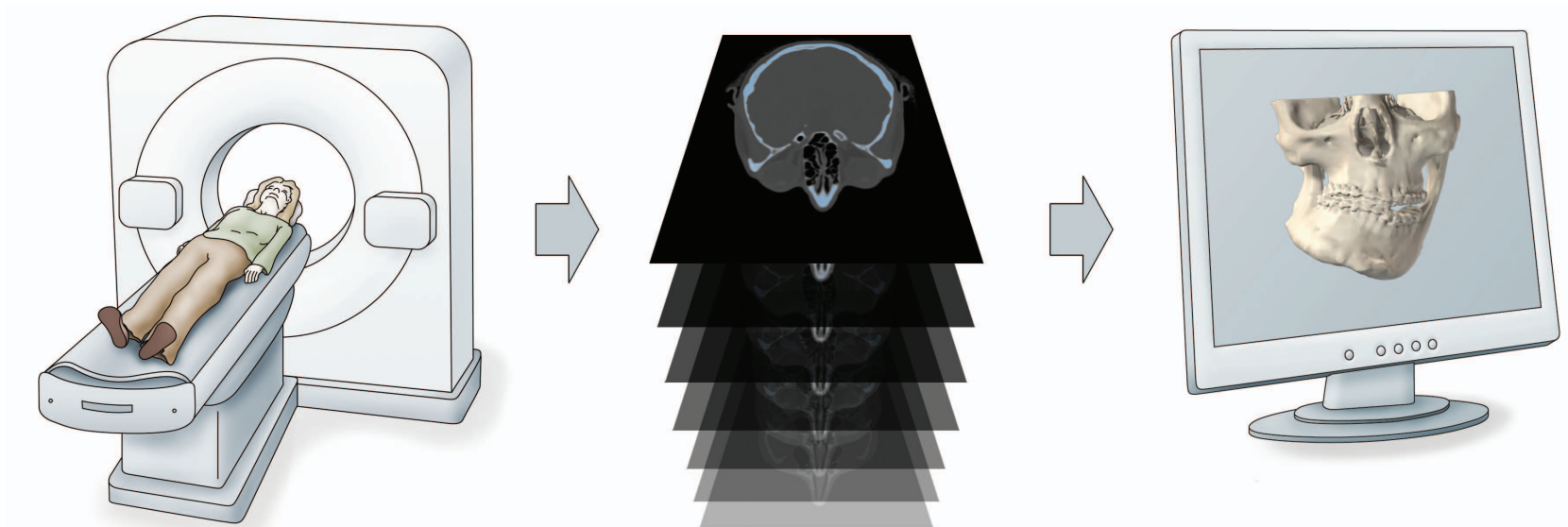


FIGURE 8-2 A, The process of anatomic modeling begins with a computed tomography (CT) scan. Axial cross-sections from the CT scan are interpolated in a computer to form a virtual three-dimensional (3D) object. This 3D computer file becomes the input to the modeling machines that produce the physical object.

Image Processing and File Formats

Once a CT scan is done, the modeling vendor will require the axial images to proceed with production of an anatomic model. Typically, the radiology center will archive this data to a CD-ROM, which is readable on most computers. Standards for the format of radiologic images have made transfer and portability much easier than it was in the past. The DICOM standard has effectively erased any problems with scanner-specific formats and proprietary compression. The axial images are first imported into specialized software written to interpolate the 2D cross-sections into a fully 3D computer model.

This is accomplished by using gray-value thresholding to identify bone or other structures and “stacking” the appropriate segmented data in one slice with corresponding slices above and below to form a 3D computer object (Figure 8-2B). From this stage, further processing can be done to eliminate scatter artifact caused by dental restorations or existing implants in preparation for modeling. The final step prior to physical modeling involves translation into an STL format file, a format originally written for the SLA process. This now universal file format contains point data for the vertices of the triangular surfaces that combine to form the shape of the

3D object. The STL file is then directed to the rapid prototyping apparatus for production of the physical model.

One drawback of using CT scanning technology is that it does not allow for discrete differentiation of soft tissue structures. For better soft tissue resolution, an MRI study might be preferred. Increasingly in the reconstructive surgery field, multimodality imaging studies are being used for diagnosis and surgical planning. This allows use of a CT for identification of bony landmarks and the MRI for isolation of the extent of some soft tissue pathology. In this light, both studies can be used and combined (Figure 8-2C).

B

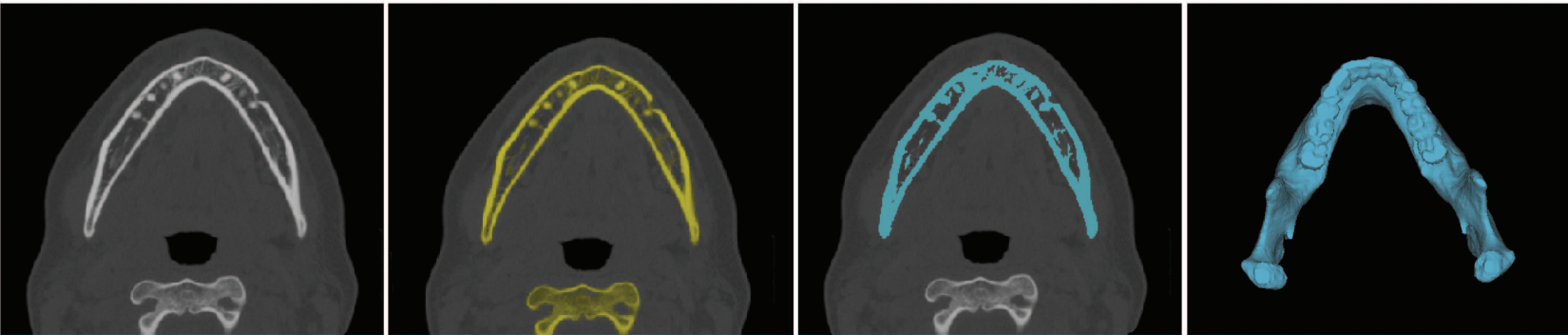


FIGURE 8-2 B, Image processing refers to the segmentation of certain objects within the medical imaging study. In this case, a computed tomography scan of a mandible is used to segment only the bone structure. First, a gray-value threshold is set, from which the computer determines all of the structures in a single slice that fall within the range of the cortical bone. From here, all unimportant structures are removed (ie, the spine) and a new “mask” is created for only the mandible. Finally, all of the segmented data for the mandible are stacked up, forming a three-dimensional rendition of the mandible.

C

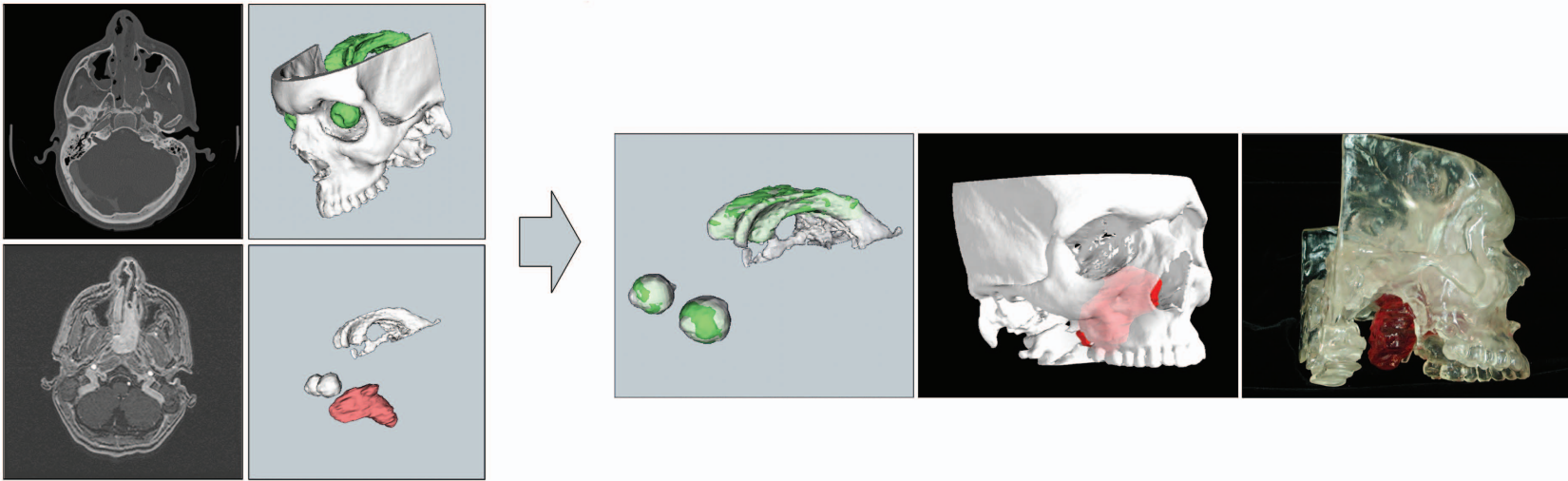


FIGURE 8-2 C, Registration of computed tomography (CT) scan and magnetic resonance imaging (MRI) data begins with imaging the same structures in both imaging modalities. In this case, a nasoethmoid tumor shows up very well on an MR image but poorly on the CT image. Structures seen in both imaging data sets are used for registration, which can include the globes as well as the ventricles. Once these objects are registered together, they are dropped out and the remaining bony anatomy and tumor anatomy are properly aligned. A two-color stereolithography model is produced, highlighting the extent of the tumor within the bony structures.

Combination of multiple studies has proven to be very useful and relies on using common points of reference present within both studies for alignment of the entire study. In a more physical manner, one can also integrate accurate dental casts into the accurate bone model for more accurate and realistic surgical planning.^{11,12}

It is advisable to follow a protocol for modeling even if a model is not required at that time, as the parameters are typically usable for clinical diagnosis and planning. This will also ensure that the data are in a format acceptable for modeling, in the event that a model is desired at a later point. The accuracy of the modeling process is usually stated as $\pm 1.0\text{ mm}$, but this is highly dependent on the input imaging data; the more accurate the imaging data, the more accurate the final model.¹³

- A typical protocol for acquiring CT images in anticipation of production of an anatomic model might be as follows:
- Slice thickness and spacing
 - 1 mm thickness $\times$ 1 mm spacing continuous axial slices (thickness of slices anywhere from 0.5 to 2.0 mm are suitable for maxillofacial models)
 - Patient positioning
 - Patient positioned supine with occlusion parallel to the gantry
 - Technical parameters
 - Field of view to include all anatomy, typically 20 to 25 cm
 - 0° gantry tilt
 - Helical (spiral) acquisition

- Standard algorithm or soft tissue algorithm
 - Limit patient motion during the scan
 - Data output
 - Most CT and CBCT scanners can be used; check for DICOM image output
- The ability to precisely plan orthognathic surgical procedures, including those using distraction osteogenesis, relies on the ability to plan using a common reference. Without knowing the patient’s natural head position (NHP), it is difficult to quantify changes and truly correct a patient’s deficiency.¹⁴ The anatomic model produced from a CT scan, if not done of the entire skull, will reflect a “horizontal reference” in the plane in which the patient was scanned.

Historically, the anatomic model has made no reference to this, but in the future, this may be possible. One embodiment of this technique would have NHP measured using some other (digital) technique and allow for integration of a colored line on the model representing the Frankfort horizontal. Use of this technique may be useful for planning cases and may become a standard of practice for anatomic modeling. This can be referenced historically when referring to a patient's model, for consideration of growth or previous surgical intervention.

Tactile Modeling Technology

Tactile modeling or rapid prototyping processes are characterized by the ability to create a physical object from computerized data in a layered fashion. This technology is primarily used in the industrial sector, allowing for design and prototyping for the automotive and aerospace industries. Because these processes were not originally intended for creation of anatomic models, special software interfaces have been developed to allow for interaction with medical image data such as CT and MRI. These software packages allow DICOM or other medical image formats to be directly imported and converted into the files needed for rapid prototyping using SLA or other processes, typically the STL file format.^{15,16} Each rapid prototyping process used for creating a model uses slightly different technology to produce the finished part. Although all of these processes are considered "additive" and are based on building 2D layers of materials into a finished model, they are all unique (Figure 8-3A). The process of SLA, albeit the first invented, is still the most widely known of all the processes and highly favored by surgeons, because it is one of very few processes that can produce a translucent model, thus enabling visualization of internal anatomy, bone thickness, air-containing sinuses, and the like.

Stereolithography

The process of SLA is based on photocuring a liquid polymer in sequential 2D layers to create a 3D object. The layers in this case are driven by the bone structure within each axial slice of the patient's CT scan. Since the SLA machinery typically produces models with layer thicknesses of 0.1 to 0.2 mm, the CT scan data is interpolated, or expanded, to create layers of this thickness. For a CT scan with 1.0 mm spaced slices, 5 to 10 model layers are created from each CT layer. A laser beam is guided onto the surface of a vat of liquid resin using the data captured by the CT scan and traces each area that will eventually be solid. When one layer is complete, the platform is lowered by one-layer thickness into the vat of liquid resin and a new layer is laser drawn onto

the previous resin layer. Each layer is adhered to the layer below, eventually creating the 3D object. The process is completed in 10 to 30 hours, depending on the size of the model being produced, and the model is then readied for shipment. Completion of the model includes removal of support structures that had been added for strength during the building process and final ultraviolet light curing to ensure a completely solid model. Two-color SLA is identical except that the second highlighted object, perhaps the tooth roots, is also "scanned" by the laser and an extra amount of ultraviolet (UV) energy is deposited into discrete areas. The application of extra UV energy activates a pigment in the resin, thus turning it a red color (Figure 8-3B).

3D Printing

3DP, although a generic title, refers to a specific technology developed in the mid 1990s at the Massachusetts Institute of Technology for production of parts using a powder-binder method. One can imagine 3DP as being like ink-jet printing in three dimensions: the process allows for production of parts from a powdered raw material by ink-jetting a liquid binder into sequential 2D layers (Figure 8-3C). 3DP, the fastest of all rapid prototyping processes, is well suited to medical modeling applications because of its relatively low cost and high speed. The technology is limited primarily to plaster-based materials and composites, which can be somewhat brittle, especially if used for surgical simulation where osteotomies will be performed on the models. Typical models produced using 3DP may require 2 to 10 hours for production and several hours for finishing after production. The plaster-based materials are opaque white, so internal visualization of structures is not available. However, one possibly significant advantage of the powder-binder process is that multiple colors can be used on machines equipped with multiple print heads. In this fashion, a machine may have four print heads and be able to output color "maps" directly onto the surface or interior of printed models. Applications for the color technology include lateralized visualization of structures such as tumors or the inferior alveolar nerve or enhanced data sets showing bone density or thickness.

Fused Deposition Modeling

The fused deposition modeling process is widely known within the rapid prototyping industry as producing the most robust parts available. This process relies on extrusion of a melted plastic material through a heated nozzle that is guided on an x- and y-axis by a motor. Once a single "axial" layer is extruded, the head is raised one-layer thickness and a new layer is extruded on top of the previous layer. In this fashion, models can be printed with fairly rapid speed and with the

possibility of multiple colors deposited through multiple heated nozzles (Figure 8-3D). Materials commonly used in FDM include Acrylonitrile Butadiene Styrene (ABS) plastic and polycarbonate. Typical medical modeling cases may require 10 to 40 hours for production based on the size of machine purchased. FDM holds the distinction for medical applications of being the only rapid prototyping machine that has received US Food and Drug Administration clearance to be placed into a clinical installation such as a clinic or hospital.

Selective Laser Sintering

The selective laser sintering (SLS) process produces parts using a high-power CO₂ laser to sinter together powder particles (Figure 3E). This process has a fairly wide choice of materials because it builds in a powdered substrate. Like SLA, this process produces individual 2D layers and then adheres multiple layers by sintering the adjacent layers. The most widely used materials for SLS are nylon-based, and the resulting model is opaque. This process has high accuracy, typically building with layer thickness similar to SLA. Parts are very strong, and other industries use parts produced by SLS for functional testing for applications ranging from wind-tunnel testing to snowboard bindings. Typical medical models produced using SLS technology may take 10 to 20 hours for production and require very limited finishing to be readied for shipment. In medicine, the use of SLS has been limited by its relatively high cost and opaque modeling output.

Multi-Jet Modeling

MJM is the newest group of machines developed within the rapid prototyping industry. These 3D printers rely on jetting of a polymer substance through modified print heads (Figure 8-3F). The result is a fast process, producing parts that can be semitransparent and in a fraction of the time required for the SLA process. Typical materials are acrylate resins, and models can be produced using ultrafine layers of less than 0.05 mm. Although this resolution is not typically needed for medical modeling applications, there are specific applications where it can be helpful, such as production of accurate teeth models. In order to accurately display a tooth's occlusal anatomy, these thin layers may be required. Models produced using the MJM processes for medical applications typically take 5 to 30 hours for production and require limited finishing before delivery. A simple analysis of each process is included in Table 8-1.

Anatomic Modeling Uses

Most commonly, physical anatomic models are produced for reconstruction following trauma,

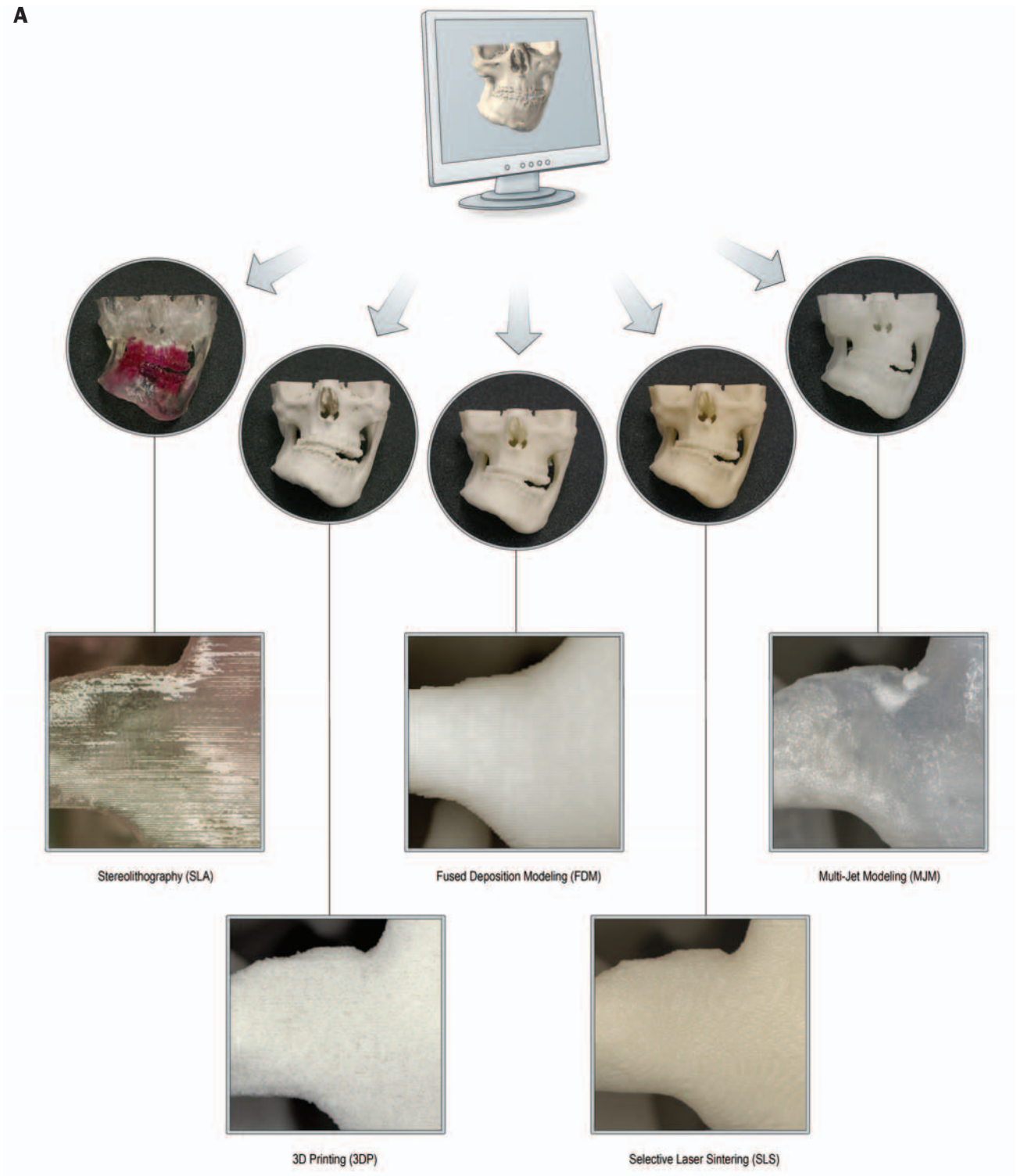


FIGURE 8-3 A, Many tactile imaging modalities exist for production of anatomic model replicas. From the computer 3D rendering, five main technologies are used, including stereolithography (SLA), 3D printing (3DP), fused deposition modeling (FDM), selective laser sintering (SLS), and multi-jet modeling (MJM). Close-up views of the area around the right zygoma reveal differences in the texture and “layering” of each different process.

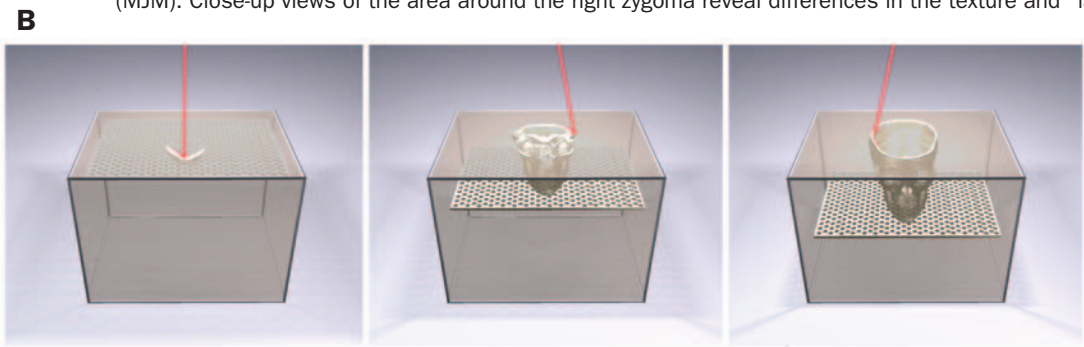


FIGURE 8-3 B, The stereolithography (SLA) process. This process produces a physical model by curing thin layers of liquid photopolymer, one upon another. In this diagram, the laser is curing subsequent axial layers to form the solid model inside of a liquid vat of resin. Two-color SLA models are made using a special acrylate-based material that can be “overcured” to a red color by the addition of higher amounts of ultra-violet energy in a specific area.



FIGURE 8-3 C, The three-dimensional printing (3DP) process. This process produced a physical model through a process of ink-jetting a liquid into a powdered base material. In this process schematic, the model is being created through deposition of a water-based formula into a plaster powder. Bound together, each thin layer of powder adheres to the layer below. When complete, the hardened model is removed from the unadhered powder bed.



FIGURE 8-3 D, The fused deposition modeling (FDM) process. This process creates a physical model by extruding a thermoplastic material through a heated nozzle. Forming two-dimensional layers by laying down a tube of material, the model is built by stepping up a small increment and forming a new layer on top of the previously extruded layer.

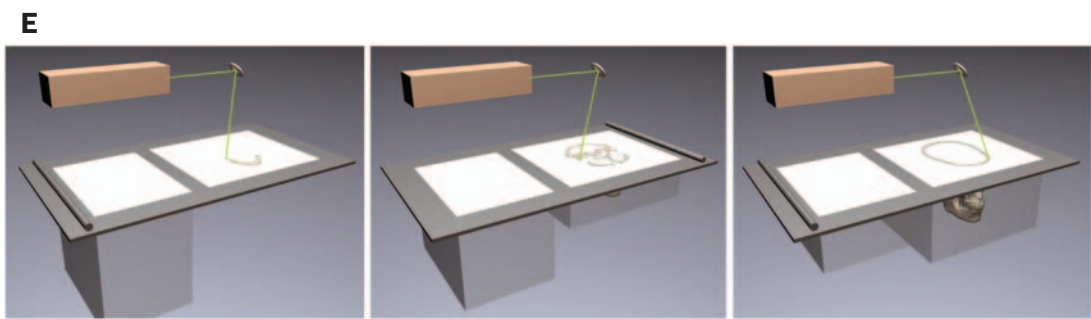


FIGURE 8-3 E, The selective laser sintering (SLS) process. This process creates physical models by the selective sintering of powdered plastic particles. In each two-dimensional layer, small particles of plastic are selectively sintered together, forming a complete layer. Then, a new layer of powder is overlaid on top of the sintered layer and the process is repeated.

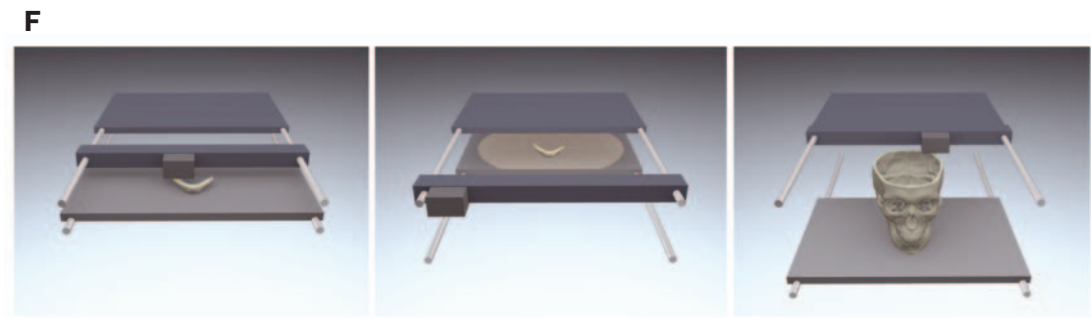


FIGURE 8-3 F, The multi-jet modeling (MJM) process. This process relies on the ink-jetting of a polymer material through jet nozzles to form a physical model. Thin layers of polymer are jetted through nozzles and cured all at once by an ultraviolet lamp. Subsequent layers are built on top of previous layers.

Table 8-1 Model Fabrication Method Comparison				
	Method	Material	Speed (est hours/skull)	Relative Model Cost
Stereolithography (SLA)	Curing of photopolymer by UV laser	Photopolymer (acrylate- or epoxy-based)	10–30	High
Selective laser sintering (SLS)	Sintering of plastic powder by CO ₂ laser	Nylon	10–20	High
Fused deposition modeling (FDM)	Plastic filament extrusion	ABS plastic	20–40	Moderate
3D Printing (3DP)	Powder-binder ink-jet printing	Plaster powder	5–8	Low
Multi-jet modeling (MJM)	Polymer or wax ink-jet printing	Acrylic polymers or wax	5–30	Low

ABS = Acrylonitrile butadiene styrene; est = estimated; 3D = three-dimensional; UV = ultraviolet.

correction of acquired or congenital dentofacial deformities, or for correcting defects resultant from tumor ablation surgery. Surgeons report the main clinical uses for these models as being (1) surgical planning, (2) surgical simulation, (3) device customization, (4) intraoperative guidance, and (5) communication both within the surgical team and with the patient.

Surgical Planning

Choosing an appropriate surgical procedure deemed to be effective for a particular patient can be difficult. Many times, surgeons are left to await the clinical picture after exposure in surgery in order to determine the best way to correct a certain problem. Accurate anatomic models can allow for preoperative choices concerning staging of procedures, choices of instruments, and choices of osteotomy sites.¹⁷ Tumor resection procedures are often planned using models to determine the best approach and impact on unaffected surrounding structures. Three-dimensional visualization of the patient's anatomy and quantification of the amount of asymmetry, trauma, or pathology are all easily realized when holding a physical model in-hand.

Surgical Simulation

Simulation of the surgical procedure is routinely accomplished using anatomic models.^{18,19} In combination with standard dental models, these models can be used for osteotomy simulation and optimization of bone segment movements. Choice of sites for screws or placement of an osteotomy will take advantage of the tactile nature of anatomic models, easily allowing visualization of nuances otherwise overlooked with traditional imaging modalities. Once osteotomies are simulated and bone movements predicted, a further step could involve the production of acrylic interpositional templates or osteotomy guides. These easy-to-fabricate guides then become the link between the tactile surgical simulation and the surgery itself.

Device Customization

Off-the-shelf devices are routinely contoured to customized anatomic models, allowing for realization of time-savings during surgery. Reconstruction bars, titanium meshes, and distractors can all be preformed to the model and then sterilized prior to surgery (Figure 8-4A). In addition, if the patient's anatomy is outside the normal scope that off-the-shelf implants cover, the surgeon may elect to have a customized implant or device fabricated on the model. These devices, although sometimes costly, are often the only method available for reconstructing extremely damaged anatomy. Patients with significant asymmetry



FIGURE 8-4 A, One of the most common uses for anatomic models is for pre-bending off-the-shelf titanium reconstruction plates. In this application, the model allows for precise adaptation of the titanium reconstruction plate before surgery, taking into account symmetry and projection. Preadaptation of the plate has also been shown to reduce operative time and allow for more confidence in the reconstruction.

also benefit from visualizing the contralateral anatomy, and if needed, a mirror-image model can be produced to allow for visualization of the patient's normal contralateral contour. An example of this technique would be an expansile mandibular lesion, which would be difficult to pre-bend a reconstruction bar around. With a mirror-image model in hand, the surgeon can optimize the symmetry and achieve the best possible reconstruction with a decrease in the time needed during surgery (Figure 8-4B).²⁰

Intraoperative Guidance

Neurosurgeons have reported the best examples of intraoperative reference using anatomic models for deep-brain procedures through the use of stereotactic frames and positioning devices.² In other specialties, models are commonly used inside the operating room for reference during surgery and for visualization in areas where exposure is limited. Certain modeling materials allow for sterilization and can be used within the sterile field (Figure 8-4C). A procedure for reconstruction of the mandibular body involving a vascularized flap can benefit from the use of

the sterile model in surgery. In this instance, the graft bone can be contoured to fit the area for reconstruction while still connected to vascular structures in the host bone, thus reducing the time between harvest and reconnection of vascular structures. Anecdotally, surgeons report that this technique saves time and likely decreases some of the risks of flap failure. Other applications include production of surgical stents for dental implant osteotomy placement, angulation, and depth control. These templates increase confidence and improve positioning for the restoring dentist to accomplish the esthetic restoration (Figure 8-4D).

Communication

A side benefit of using anatomic models is their ability to easily and effectively facilitate communication surrounding the case. Today's multidisciplinary teams reconstructing large maxillofacial defects are often comprised of multiple specialists. Accurate anatomic models allow for concise communication of the patient's condition, proposed procedure, and other important factors relevant to different members of the team. In very

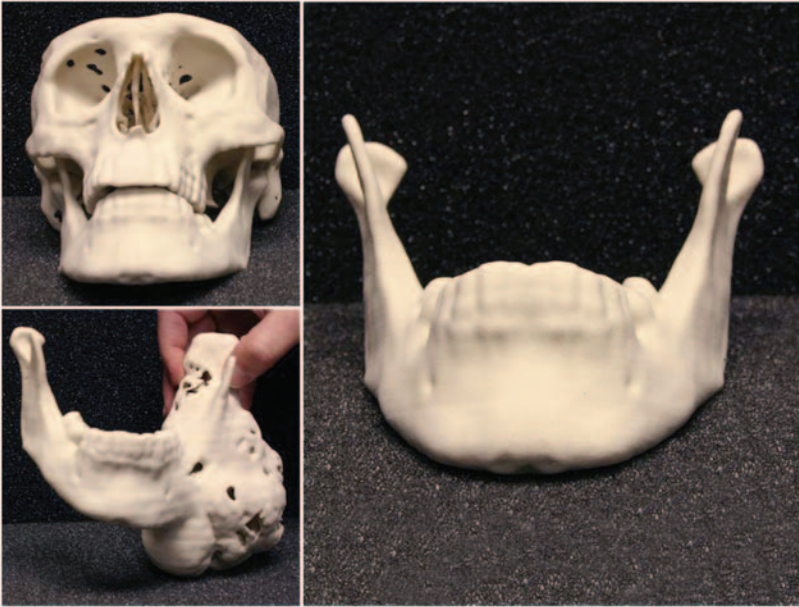
B

FIGURE 8-4 B, A large lesion of the left mandible (*bottom left picture*) was modeled using three-dimensional printing techniques. To aid the surgeon's use of modeling technology, a "normalized" mandible (*right and top left pictures*) was produced. This normalized mandible allowed for precontouring of the graft and plating that would be used in a more symmetric shape than what was currently present.

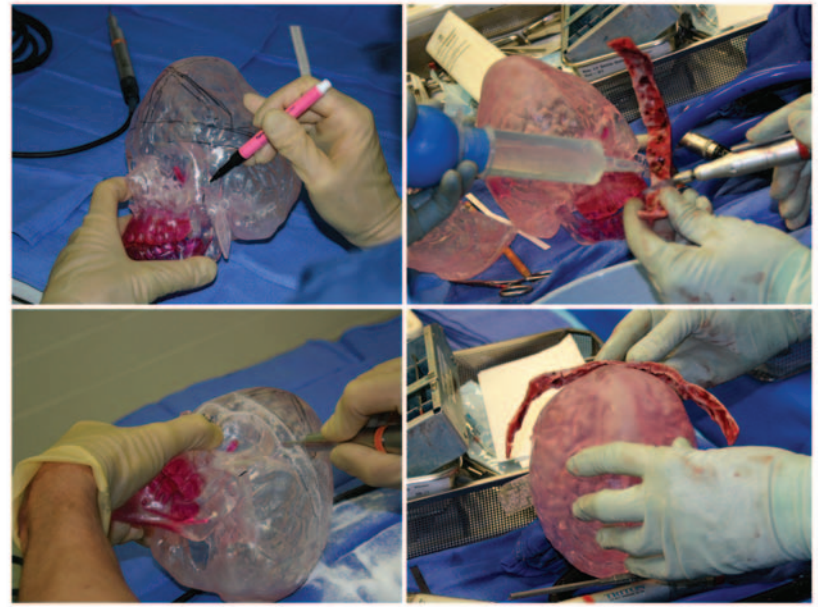
C

FIGURE 8-4 C, Certain two-color stereolithography modeling materials can be sterilized and used for reference during surgery. This case, showing a frontoorbital advancement, relied on precise osteotomies that were planned on the model. In surgery (*bottom right*), the model was used to guide reshaping of cranial bone used to recontour the forehead.

D

FIGURE 8-4 D, Tactile models are now routinely used for planning dental implant cases. Using models, the implant positions, depths, and placement are planned. The plan is transferred to the patient using drill guides that are bone-borne, tooth-borne, mucosa-borne, or some combination of these.

complex procedures, the use of models has become standard for doing practice runs of entire procedures including nursing, anesthesia, and the like. Surgeons also report that the models are very useful and powerful tools for patient communication and informed consent. Holding a model of the patient's anatomy allows for appreciation of the complexity and extent of surgical procedures that would not be fully realized using an off-the-shelf generic skull, as is commonly used.

Specific Uses Surrounding Distraction Osteogenesis Procedures

Surgeons experienced in using distraction osteogenesis for treatment of craniomaxillofacial deficiencies are well aware of the need for proper planning of such procedures. The 3D nature of this process requires a good understanding of (1) the principles of distraction osteogenesis of the facial skeleton, and (2) how to apply those principles to the 3D anatomy of a given patient. Factors affecting the outcome of distraction osteogenesis procedures include the quantity of bone, the quality of bone, location of osteotomies, avoidance of vital structures, and vectors of distraction.^{21,22} Some of these may be aided by accurately translating the science of distraction osteogenesis to the unique anatomy of the patient being treated. Although standard cephalometric tracings and predictions may provide part of the solution to planning, they leave out some important factors relating to scale, symmetry, and

the unique anatomy of any given patient. A fairly standard mandibular advancement case, when performed with orthognathic techniques, may be more complex when performed with distraction because of these unique factors. The surgeon must not only visualize the surgical intervention but also the movements of the bone segments over time to their desired resting places. This reliance on bony movements in three dimensions must be carefully visualized and realized prior to surgery to avoid possible complications with undesired movements.

Visualization of vital structures such as tooth roots, impacted third molars, tooth buds, and the inferior alveolar nerve canal in the mandible can be very important to the planning of a mandibular distraction case (Figure 8-5A). Standard panoramic radiographs or lateral cephalometric radiographs provide information on their locations, but only in two dimensions. The position of the nerve buccal versus the lingual may play a major role in the osteotomy to be used for a particular case. This need is heightened when abnormal skeletal anatomy is involved. Positioning of fixation for the distraction device also relies on being close to these structures. With the growing realization that many distraction procedures can be accomplished with smaller intraoral devices, the surgeon is challenged to predict where all these structures are without the aid of a wide-open surgical field. The more minimally invasive the procedure, the more a need arises for accurate and precise 3D preoperative planning.

Distraction Osteogenesis Modeling Examples

The uses of anatomic models for distraction osteogenesis procedures are similar to other



FIGURE 8-5 A, A benign lesion of the mandible required resection en bloc of a large segment of the right mandible. A transport distraction osteogenesis device is shown, adapted to the model in advance of the surgery. Using the model for tactile planning allows for visualization of ideal fixation points as well as projected time for distraction to be completed.

application areas. The three main areas of use are (1) for visualization of the patient's anatomy, (2) for simulation of the distraction process (including pre-bending of devices), and (3) for intraoperative reference during the procedure when installing the devices. Additional benefits such as using contralateral anatomy for reference, simulating concomitant procedures on the model, and using the model for patient education are also seen (Figure 8-5B).

Using the model as a tactile aid for planning allows the surgeon to visualize the entire anatomic structure of interest and compare it with other surrounding structures with relative scale.²³ Viewing a standard 3D CT scan allows for visualization, but lacks the ability to fully appreciate the anatomy and the scale and size of certain anatomic features or landmarks. Looking at a 1:1 scaled anatomic model of a patient's anatomy allows for both a tactile object and a correct spatial representation of the anatomy.²⁴ In unilateral distraction osteogenesis, for example, the surgeon can compare the contralateral side in order to judge distance, angulation, bone quality, bone quantity, and other factors that are hard to recognize on 2D or even 3D CT scans. Furthermore, a bilateral case may involve issues with asymmetry and correction that are best visualized on a scale model of the patient's facial skeleton.

Models are not only useful for visualization purposes. Their use can be extended to allow

them to become the basis for surgical simulation.^{25,26} Osteotomies can be performed on the model, avoiding vital structures such as tooth roots and the inferior alveolar nerve, and the distraction devices can be prepared using the model. Models allow for a preprogrammed distractor to be bent for the patient before surgery, using a stock device (Figure 8-5C). Vector planning is also made possible and optimized using a model before surgery. Maxillary or midface advancement with intraoral distraction devices also benefit from pre-bending of the anchor plates (Figure 8-5E). Using the model for pre-bending of the device(s) allows for a shorter surgical procedure with more predictable movements.²¹

Customized anatomic models also offer benefits when used in conjunction with extraoral distraction devices. In a sample case, using the model as a guide, the multi-vector distractor is programmed to follow the exact path that will allow the condylar anatomy to seat properly into the glenoid fossae (Figure 8-5D). Coloration used in the model to highlight the teeth roots, impacted third molar, and inferior alveolar nerve allows for optimization of the placement of the osteotomy. Bone stock is also evaluated at this step, allowing the surgeon to choose an area with excellent bone stock and thus tailor the osteotomy to maximize the surface area of bone within the osteotomy site. The combination of model surgery combined with adaptation of the devices allows for much

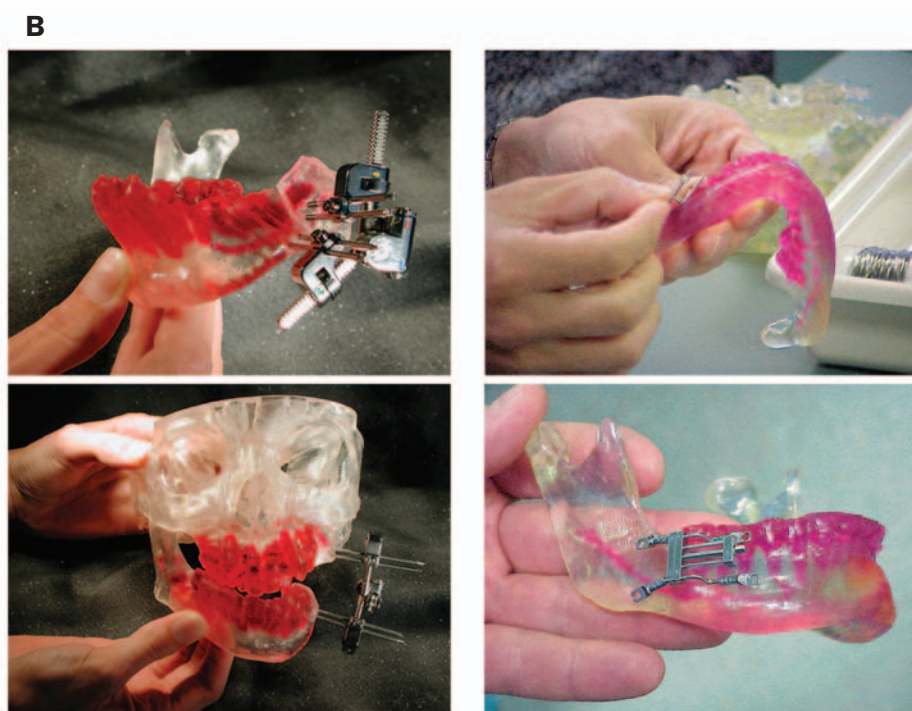


FIGURE 8-5 B, Off-the-shelf distraction osteogenesis devices are shown being adapted on two-color stereolithography models. With selective coloration of tooth roots and the inferior alveolar nerve canal, the surgeon can be confident in the placement of screws to avoid these vital structures.

C

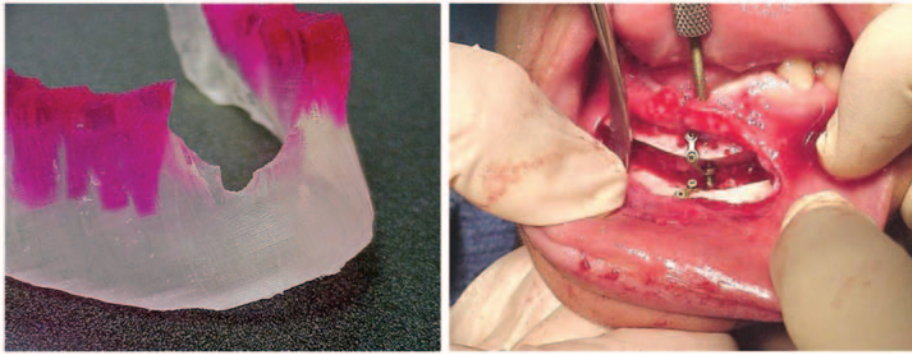


FIGURE 8-5 C, A two-color stereolithography model is used to plan device placement and osteotomy design for an anterior alveolar ridge augmentation procedure. The model allowed for optimization of the osteotomy and avoidance of the nerve roots, which were selectively colored.

D

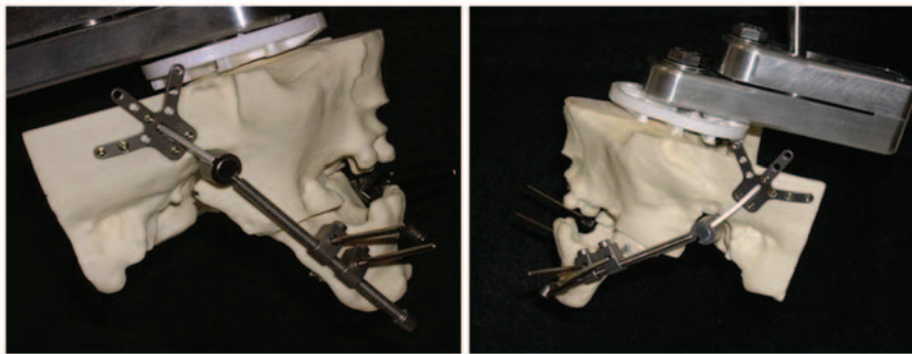


FIGURE 8-5 D, An external fixation device is shown being adapted to the anatomy of a patient suffering from bilateral temporomandibular joint bony ankylosis. Following a gap arthroplasty, this patient's anatomy required a complex device that would be contoured to fit the temporal bone and the ramus of the mandible. The model proved useful for adaptation of the titanium plates.

smoother installation and advancement of the distracted segment.

With the advent of distraction hardware that is made of resorbable polymer, a sterilizable model has been an invaluable aid in the operating room. With the sterile model, the plates can be adapted in a sterile field on the back table, which allows for surgical time-savings. This allows the surgeon to limit the amount of time that is wasted in the procedure and optimize the results with intraoperative contouring of the device on the model.

One goal of distraction osteogenesis procedures is production of bone in a 3D shape to restore function and reconstruct facial esthetics. Because this process is not just 2D, it requires the use of 3D imaging aids in planning and preparing for cases. Accurate anatomic models created using CT scan data and SLA are used for planning the complex movements of the distraction process before surgery. This careful planning leads to the shortening of surgical time required to place the device, and a more predictable surgical outcome.²¹ Correct angulation of the device(s) is absolutely necessary to avoid giving the patient an anterior open bite, and for obtaining the optimum result from the distraction procedure.

Customized Prosthetics

One of the first great applications that arose from the use of replica models of patient anatomy was their use as an implant customization tool.²⁷⁻²⁹ Alloplastic implants and prostheses ranging from polyethylene ears to titanium subperiosteal dental frameworks were all fabricated in a customized manner using the model as a template. The typical process for fabricating these implants would be to produce a physical model and then hand design the implant in wax or clay. From there, the

E



FIGURE 8-5 E, A stereolithography model of the maxilla was used for precontouring maxillary distraction devices. The bilateral devices required extensive contouring prior to their proper installation. Preoperative and postoperative photographs indicate the successful outcome achieved with buried intraoral maxillary distraction devices.

wax could be invested and cast into something such as silicone or polymethylmethacrylate. Soon cobalt-chrome and titanium were being cast and used all over the body, from implants for revision hip surgery to customized cranial plates. Today, many customized implant materials are readily adapted using anatomic modeling technology. These include titanium alloy, cobalt-chrome, polymethylmethacrylate, polyethylene, porous methylmethacrylate, solid silicone, and others. In the head and neck area, several applications for customized prostheses produced using rapid prototyping technology have stood the test of time and include customized cranial plates for large defects (Figure 8-6A), facial reconstruction implants (Figure 8-6B), and, customized total temporomandibular joint replacements (Figure 8-6C).

The creation of customized prostheses using anatomic models takes advantage of (1) the tactile nature of the model, (2) the accurate 1:1 representation that the model provides, (3) use of contralateral anatomy (when present), and (4) the ability to quickly judge bone volume and thickness in areas of fixation. Of these four factors, the most important seems to be the tactile nature of the model and its accurate anatomic representation. As software driven surgical simulation packages become available over the coming decade, they will all lack the ability to have tactile interaction with the patient’s medical imaging data. Only a physical anatomic model can provide the physical tool needed to take a plan for a customized prosthesis and produce it in physical form. Mirror imaging is increasingly used for either severely distorted anatomy or in cases where anatomy

has previously been removed. This technology and the physical models produced in a mirrored fashion can make a major difference in restoring symmetry.

Future Trends

High-technology fields like the rapid prototyping field are constantly evolving to provide more benefit at a faster pace with less cost. This effect spills over into the medical modeling side as well.³⁰ Even at present, companies are using faster machines to produce parts that are less expensive than traditional STL models. Processes like 3DP hold much promise to bring anatomic modeling into much wider acceptance within the surgical specialties, by providing models for less cost. In the future, it is expected that medical imaging will

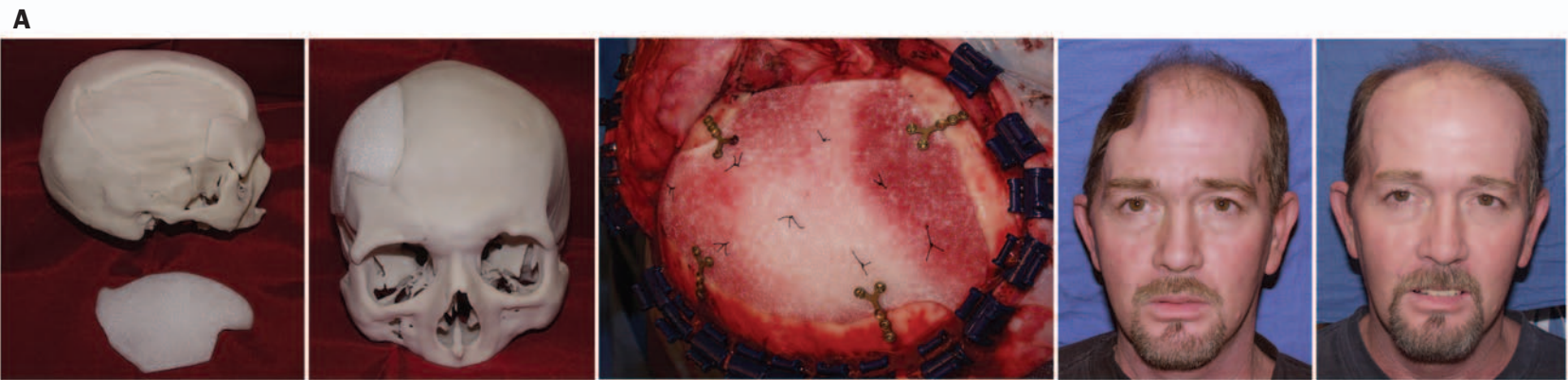


FIGURE 8-6 A, A patient with a large posttraumatic cranial defect is treated with a custom-made cranioplasty prosthesis. Using the computed tomography scan, a three-dimensional printing model was created to aid manufacturers in creating a custom-made porous methylmethacrylate prosthesis. The prosthesis was able to make the surgery proceed much faster than with traditional techniques while providing the patient with an excellent esthetic result.

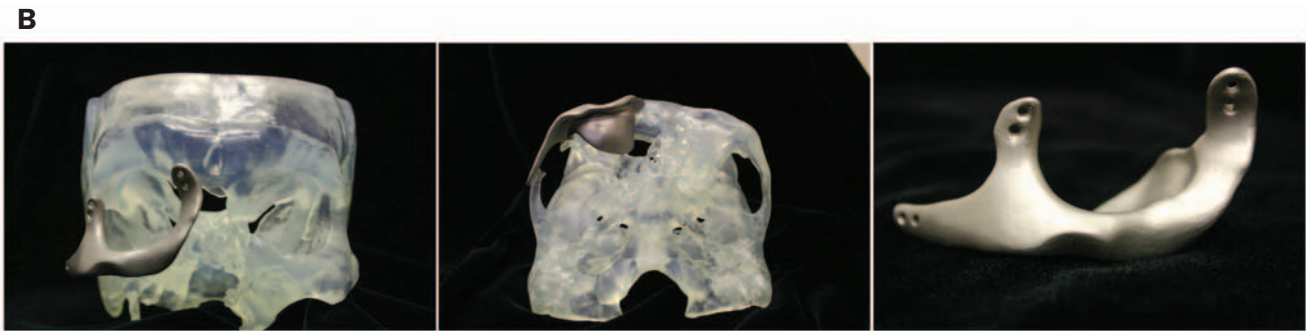


FIGURE 8-6 B, A patient with a previous hemimaxillectomy is a candidate for a custom-made titanium implant produced with electron beam melting. This titanium alloy implant was computer designed and “printed” in a layered process called electron beam melting, which transforms titanium powder into solid objects. The implant has been optimally designed to be lightweight while achieving proper symmetry of the patient’s zygoma and zygomatic structures.

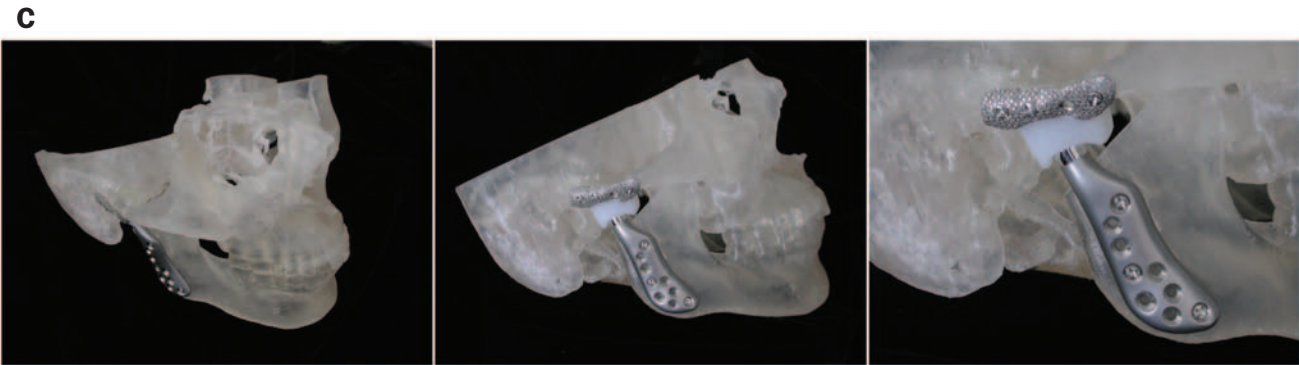


FIGURE 8-6 C, Customized total temporomandibular joint implants can be designed and fabricated using stereolithography anatomic models. Using the model allows for more accurate design and production of patient-matched implants that are able to compensate for symmetry and functional issues. Reproduced with permission from TMJ Concepts, Inc, Ventura, CA.

provide more useful data on bone quality, function, and the like. Full-color models in opaque or translucent materials will be available to take advantage of displaying this new and expanded information. Further adoption of the technology by the third-party insurance industry will also allow for the modeling industry to expand into further clinical indications.

In-Office Scanning and Model Fabrication

Perhaps the largest shift in recent years affecting the industry for anatomic modeling and technologies using anatomic modeling is the adoption of in-office scanning. Surgeons using CBCT in their offices to readily capture high-quality data are providing their patients a higher level of care and confidence. Companies such as Imaging Sciences International (Hatfield, PA) and their i-CAT CBCT scanner are giving surgeons access to this technology at a very fair price, not much more than a traditional cephalometric radiography machine (Figure 8-7A). The next portion of this trend will include some way to output usable portions of this data in an office setting. Already, several companies are investigating this field and planning production of machines that are inexpensive, produce robust parts, and do this in a quick time frame (Figure 8-7B). Dental implant stents and limited models of maxillofacial anatomy are likely the first target audience for these machines, but as time moves on, they could well be used for primary trauma intervention, something unachievable today because of the time associated with production of models.



FIGURE 8-7 B, With the possibility of in-office scanners has also evolved the possibility of in-office modeling systems. Several systems are coming available that allow for fabrication of anatomic models in a surgeon's office setting. These new machines are less costly than traditional stereolithography machines and produce models of adequate quality for planning many procedures. Reproduced with permission from 3D Systems Inc, Valencia, CA (left) and Z Corporation, Burlington, MA (right).

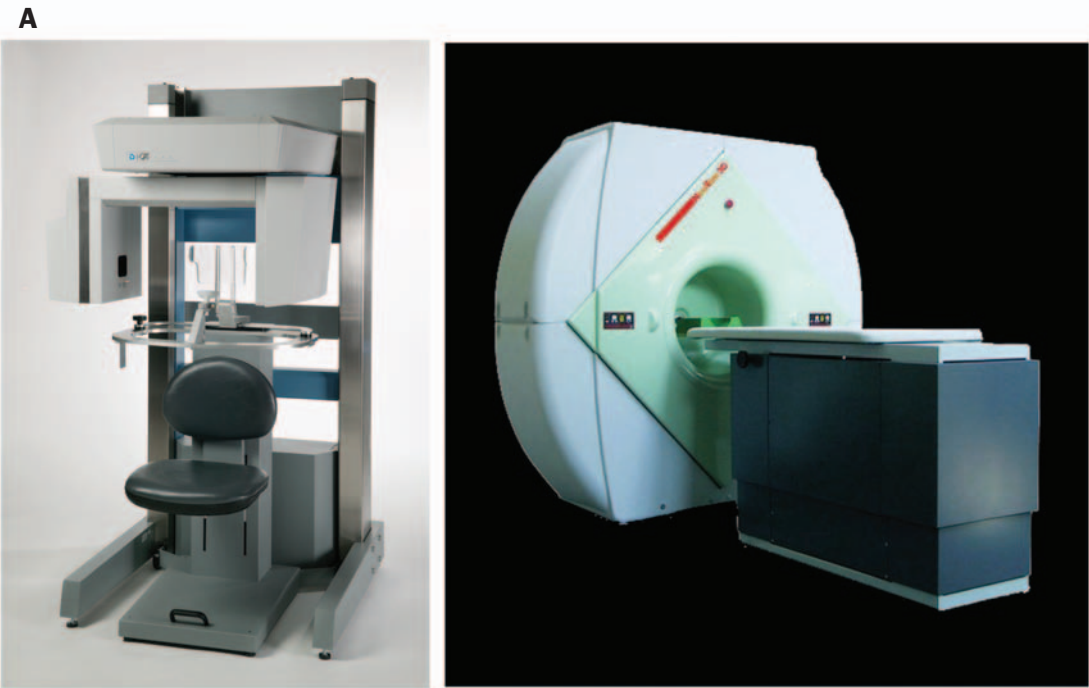


FIGURE 8-7 A, In-office scanners such as these cone-beam computed tomography (CBCT) devices are becoming more popular in the dental specialties. These compact, relatively inexpensive units allow for the surgeon to obtain high-resolution images suitable for anatomic modeling in an office setting. Short acquisition times along with lower per-scan costs have led to this method becoming increasingly popular among dental specialists. Reproduced with permission from Imaging Sciences Inc, Hatfield, PA (left) and AFP Imaging, Sarasota, FL (right).

Template-based Surgery

A major future trend will combine the power of software-based planning with physical model creation. Template-based surgery has been reported and will continue to find use for easy guidance in surgery following thorough planning in specialized software packages.^{31–33} From that optimized plan, a surgical template can then be created using rapid prototyping technology, to accurately translate the plan to the actual surgery. Until the time that this process is available, today’s physical anatomic modeling will continue to be the gold standard for planning complex procedures (Figure 8-7D).

Digital Fabrication

With more and more designs of implantable prostheses being done in the computer instead of by hand, it makes sense that “digital” fabrication techniques will continue to arise to take the digital data and directly output a device or implant. Processes such as electron beam melting (EBM) show major promise in this area, allowing for production of fully dense metallic parts in titanium alloy or cobalt-chrome to be fabricated (Figure 8-7C). Scaffold designs can be printed in the same manner, allowing for minimized weight and optimized design for osseointegration. Other technologies are in development for direct printing in resorbable polymers and ceramic biomaterials. There is little doubt that tissue engineering will use some of these techniques to realize tissue and organ “production” at a point not too far into the future.

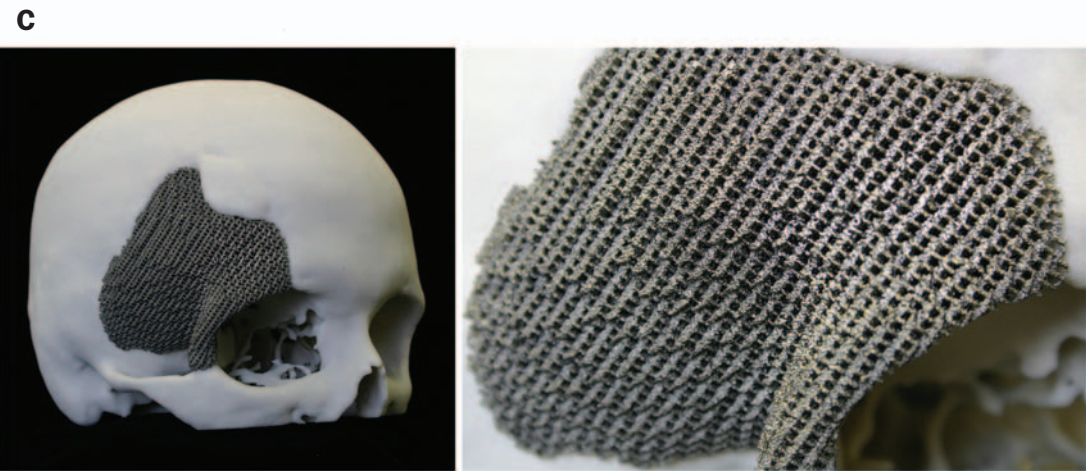


FIGURE 8-7 C, Customized production of titanium plates is now carried out with a process called electron beam melting. This process has the potential to produce implants in biocompatible materials such as cobalt-chrome and titanium, in either solid form or in a porous structure. Shown is an implant for an orbital reconstruction case produced in a porous titanium construct.

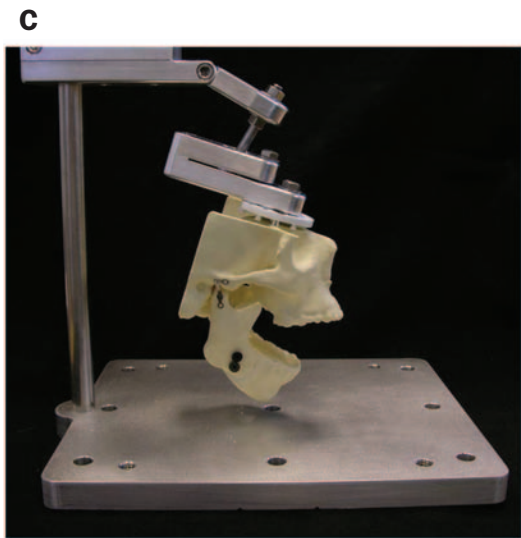


FIGURE 8-7 D, Medical models that have been modified to include accurate occlusal teeth anatomy will serve as a basis for “all-in-one” model surgery planning. This photo shows a model being used for orthognathic surgery and customized intermediate splint creation.

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Fabricating a Surgical Wafer Splint by Three-Dimensional Virtual Model Surgery

Seung-Hak Baek, Seok-Jin Kang, William H. Bell, Stephen Chu and Hwa-Kyu Kim

Precise model surgery for three-dimensional repositioning of the maxilla and mandible is complex, lengthy, and tedious. One of the many present day problems associated with the delivery of orthognathic surgery treatment, relates to excessive time spent with planning for and executing three-dimensional model surgery. For many complex two-jaw surgery cephalometric tracing cases model surgery studies require more of the surgeon's time than the surgery itself. Many of the complications associated with orthognathic surgery are related to incorrect positional changes of the jaws and teeth as a consequence of incorrect model surgery. Meticulous three-dimensional surgical planning in concert with anatomic model surgery (use of the Erickson model platform) minimizes such errors. Present day sophisticated technology will both confirm the surgical plan and provide the surgeon with quantitative information at surgery. These methods eliminate the need to manually and laboriously fabricate splints on sectioned plaster models.

It is necessary to mount the dental casts into the articulator to investigate the degree of jaw deformity, coordination and alignment of the upper and lower dental arches, and severity of the occlusal plane canting in three dimensions.¹⁻⁴ To simulate two-dimensional cephalometric tracing paper surgery into three-dimensional reality, model surgery must be done to decide how much and in which direction the maxilla and/or mandible should be moved. The final result of this model surgery is a surgical wafer as a fixation medium to stabilize the jaws.

Limitation of Conventional Manual Model Surgery

A surgical wafer can be made by conventional manual model surgery (MMS) according to the surgical treatment objective (STO).^{5,6}

The procedure of MMS is as follows: (1) draw the reference lines on the casts; (2) measure the distance between the teeth and the reference lines using calipers or an Erickson platform (height gauge); (3) section the segments of the casts; and (4) move the segments according to the STO. MMS contains potential errors, such as (1) errors in the placement of reference lines on the casts and (2) errors in measuring the surgical displacement of segments. Moreover, the most difficult part of MMS during two-jaw surgery is repositioning the maxilla in all three planes of space into the desired location. Sometimes its accuracy cannot be guaranteed.

Therefore, MMS has the possibilities of allowing some theoretical errors and inaccuracies in terms of the amount and direction of the surgical movement, especially in complex surgery.⁷ If there is inaccurate simulation of surgical movements in the plaster casts, fabrication of the surgical wafer would summate all of the errors of the previous stages. Eventually, it can cause problems of esthetics and function.^{6,8}

To reduce error from MMS, a change in the surgical sequence and use of special instruments, such as the orthognathic relator (Panadent, Grand Terrace, USA) and the model repositioning instrument (SAM, CA Munich, Germany), have been introduced.^{7,9-17} However, it is difficult to use them owing to complex instrumentation and limitations in vector control for multiple-piece maxillary osteotomy or severe occlusal plane canting correction cases.

Limitation of Rapid Prototype Model Surgery Using Three-Dimensional Computed Tomographic Data

Craniomaxillofacial images from three-dimensional computed tomography (CT) can be reformatted and reconstructed into a

three-dimensional structure, which can be materialized into a rapid prototype (RP) model (Figure 9-1).¹⁸ This three-dimensional RP model can be used for three-dimensional cephalometric measurements and surgical simulation.¹⁹⁻²¹ However, there are several points to be considered when using RP model surgery.

First, because the main constituent of it is starch, it is difficult to do an accurate manipulation. Second, the slice thickness of three-dimensional CT data has a limitation in its use for reconstruction of the occlusal surface. Therefore, its accuracy for surgical wafer fabrication is not sufficient. To overcome this problem, a method that combines the RP model of the maxilla and mandible with the occlusal surface from dental casts or resin duplicates has been proposed. But owing to inaccuracies in matching the jaw and dental model, the combined method is presently not adequate for making an accurate surgical wafer (Figure 9-2). Therefore, it is questionable to use it in the daily practice environment in terms of time and accuracy.

Three-Dimensional Virtual Model Surgery

The human body, especially the head and jaw, has a complex structure. To acquire precise information, to diagnose the jaw deformity, and to plan surgery, it is necessary to do so in three-dimensional concepts. Therefore, there is a strong need for three-dimensional virtual model surgery (VMS) to support orthodontists and surgeons with accurate surgical simulation in spite of individual variation in dexterity or complex variation in model morphology. Recently, the Orapix system (KCI, Seoul, Korea) was developed for three-dimensional VMS for accurate and objective measurement and surgical simulation for orthognathic surgery.²² Because replacement

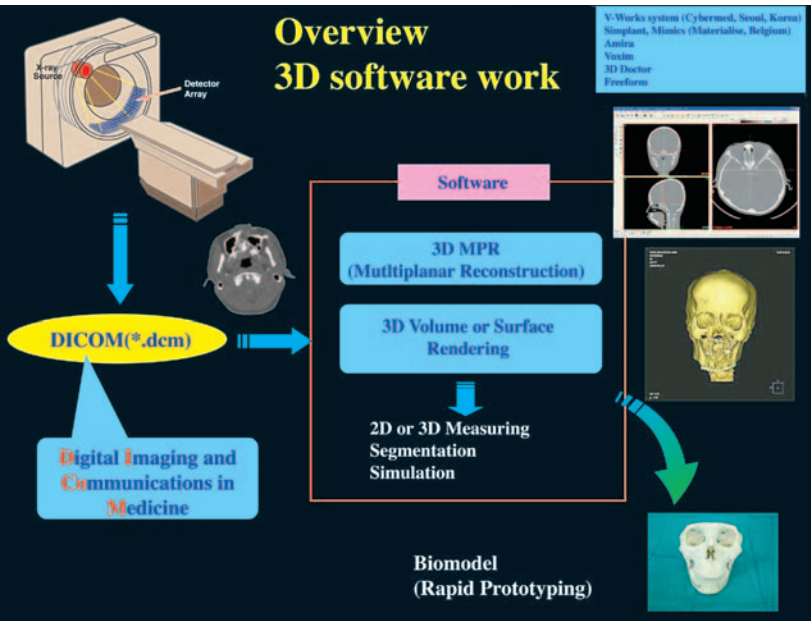


FIGURE 9-1 A craniomaxillofacial three-dimensional computed tomographic image can be reconstructed into a three-dimensional structure, which can be materialized into a rapid prototype model.

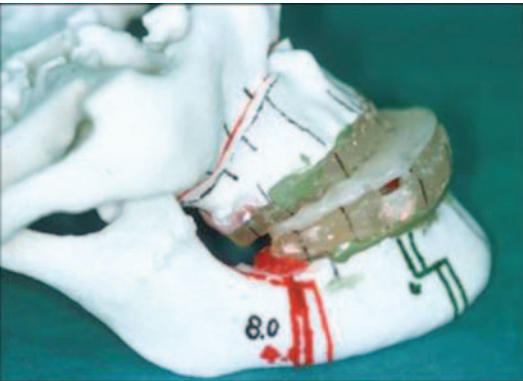


FIGURE 9-2 A method that combines the rapid prototype model of the maxilla and mandible and occlusal surface from dental casts was proposed.

of the maxilla and/or mandible can be done in an accurate way in terms of the amount and direction, fabrication of the virtual surgical wafer is also possible. Therefore, the authors report how to do VMS and to fabricate a surgical wafer in a complex two-jaw orthognathic surgery case. As a brief summary, the procedure for three-dimensional VMS is as follows: (1) mounting of three-dimensional virtual models of the maxilla and/or mandible in a three-dimensional virtual articulator; (2) sectioning or replacement of three-dimensional virtual models according to the STO; (3) fabrication of the three-dimensional virtual surgical wafer; (4) construction of the surgical wafers using the stereolithographic technique; and (5) application of the surgical wafers to the patients.

Case Summary

The patient (H.C.K.) was 21 years 6 months old, and his chief complaints were mandibular protrusion and facial asymmetry. Diagnosis was given as follows: Class III malocclusion, anterior crossbite, temporomandibular disorder (clicking sound on both sides), and facial asymmetry to the right side.

The treatment plan was a combination of orthodontic treatment with orthognathic surgery. Preoperative orthodontic treatment consisted of the extraction of the maxillary first premolars, decrowding of the maxillary incisors, alignment of the dentition, and intrusion of the maxillary second molars to prevent premature contact with the mandibular molars. At the end of the preoperative orthodontic treatment period, assessment for surgical planning was done. Preoperative data were as follows: facial (Figure 9-3) and intraoral



FIGURE 9-3 Preoperative facial photographs. Note the concave profile with the protrusive mandible, acute nasolabial angle, and chin point deviation to the right side.

photographs (Figure 9-4), an orthopantomogram (Figure 9-5), a lateral cephalogram (Figure 9-6, Table 9-1), a posteroanterior cephalogram (Figure 9-7), and mounting of the models on the semiadjustable articulator (Figure 9-8).

The maxillary and mandibular casts were mounted with facebow transfer and a bite registration was taken in centric occlusion (CO) (see Figure 9-8). In this patient, there was no severe centric relation (CR) CO discrepancy; therefore, the CO bite was used.

After assessment of preoperative records, STOs of the lateral and posteroanterior cephalometric tracings were set up as follows (Figure 9-9):

Maxilla

- Three-piece osteotomy for closure of the extraction space of the maxillary first premolar and widening of the bilateral posterior segments to correct the buccal crossbite (Figure 9-10)
- Midline correction with rotation of the maxilla
- Superior repositioning of the posterior segment (1.5 mm upward repositioning of the mesiobuccal cusp tip of the maxillary first molar). The center of rotation was located at the bracket slot of the maxillary central incisor.

Mandible

- Setback with intraoral verticosagittal ramus osteotomy (IVSRO) (left side: 9 mm; right side: 5 mm)²³
- Midline correction with rotation of the mandible

In this case, bilateral expansion and distal-lateral rotation of the posterior segments in the three-piece maxilla could resolve the transverse deficiency of the maxilla. A Class II molar relationship could be attained after extraction



FIGURE 9-4 Preoperative intraoral photographs. The upper first premolars were extracted to correct dental compensation of the upper incisors. The spaces between the upper canine and second premolar were partially closed until the inclination of the upper incisors was normalized. The upper first and second molars were derotated to acquire a Class II molar relationship using the lower second molar brackets.



FIGURE 9-5 Preoperative orthopantomogram. The lower posterior teeth were uprighted. The roots of the upper canine and second premolar were angulated to allow for the osteotomy cut.



FIGURE 9-6 Preoperative lateral cephalogram. The patient showed a normodivergent facial pattern, a protrusive mandible (SNB, Pog to N perp, Wits), a well-developed mandible (ramus height, body length), labioversion of the upper incisor axis, improved lower incisor axis, and an acute nasolabial angle.

Table 9-1 Measurement of Preoperative Data Variables in the Lateral Cephalogram		
Measurement	Mean	Preoperative
SNA (°)	81.77	83.84
SNB (°)	80.22	86.26
ANB (°)	1.78	−2.42
A - N perp (mm)	1.1	7.42
Pog-N perp (mm)	−0.3	20.32
APDI (°)	85.98	99.59
ODI (°)	73.30	56.77
FMA (°)	26.78	19.01
Facial height ratio (%)	66.37	69.92
Ramus height (mm)	54.92	68.63
Mandibular body length (mm)	78.72	87.23
Body to ACB ratio	1.08	1.23
U1 to FH (°)	116.52	123.75
IMPA (°)	90.2	89.94
Interincisal angle (°)	126.19	127.3
Nasolabial angle (°)	93.2	64.93

ACB = anterior cranial base; APDI = anteroposterior displasia; FH = Frankfort horizontal; FMA = Frankfort mandibular plane angle; IMPA = incisor mandibular plane angle; ODI = overbite depth indicator; U1 = upper incisor.



FIGURE 9-7 Preoperative posteroanterior cephalogram. The mandible was deviated to the right side.



FIGURE 9-8 The casts were mounted on a semiadjustable articulator with a facebow transfer and centric occlusion bite registration. The maxillary and mandibular models were able to be positioned in three dimensions to mimic the patient's position. The vertical and anteroposterior reference lines were drawn on the casts. There was rotation of the maxilla and mandible in reference to the midline of the articulator.

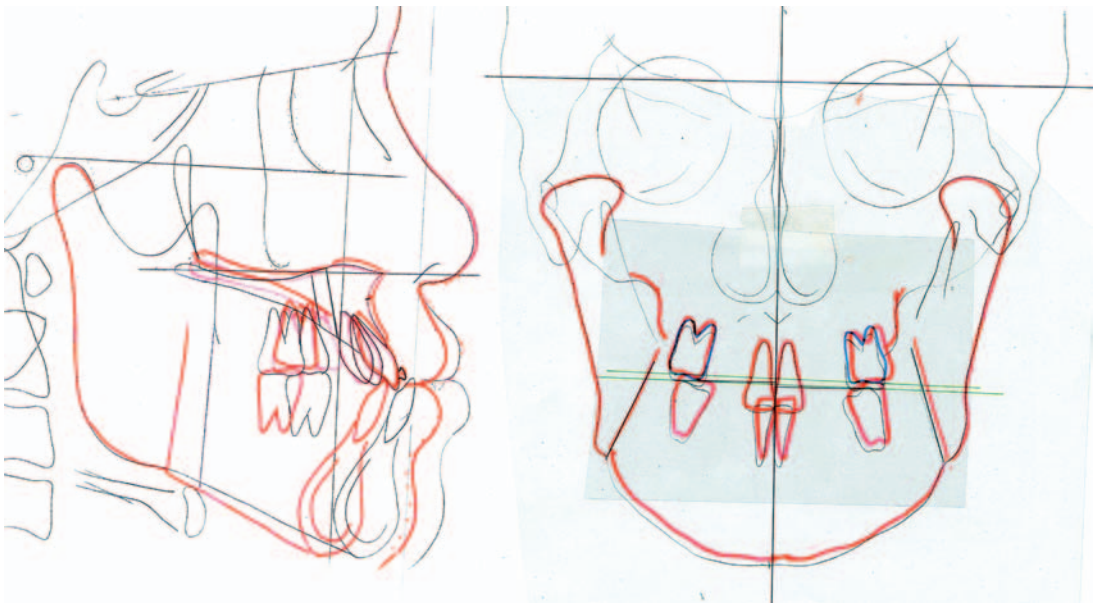


FIGURE 9-9 Surgical treatment objectives (STOs) of the lateral and posteroanterior cephalogram tracings. The black line stands for preoperative tracing and the red one for the STO.

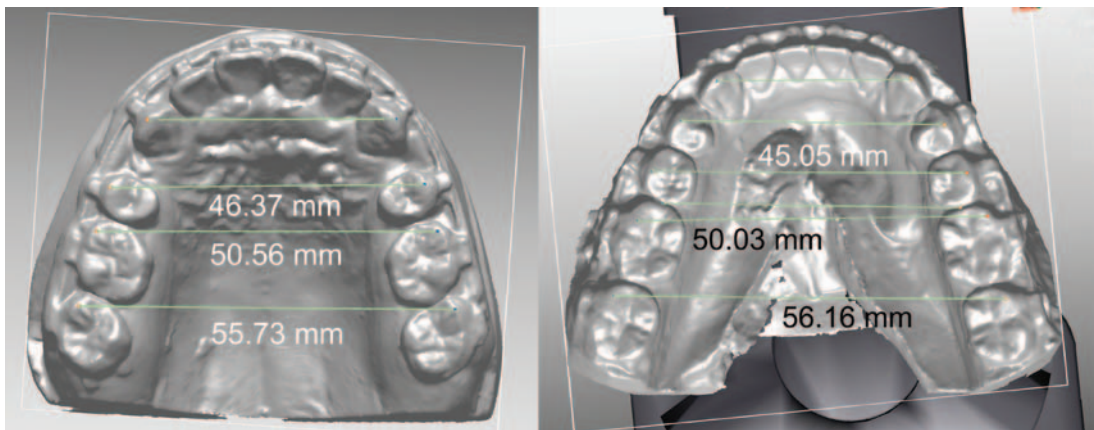


FIGURE 9-10 The transverse deficiency of the posterior segments in the maxilla was significant when compared with the mandibular dentition.

space closure of the maxillary first premolars (Figure 9-11).

MMS and Its Limitations

The steps in construction of a combined two-stage splint^{12,24} for a patient planned for two-jaw surgery involving a three-piece Le Fort I osteotomy and mandibular setback through IVSRO are as follows (Figures 9-12 though 9-18): As stated previously, the procedure of MMS is a laborious and lengthy work process and requires a lot of time. Therefore, it is difficult to perform several surgical reposition options when planning orthognathic surgery. MMS may be inaccurate in several aspects. The step of sectioning the plaster



FIGURE 9-11 A Class II molar relationship and normal buccal overjet were established after space closure of the maxillary first premolar and distal-lateral rotation of the posterior segments in the three-piece maxilla.

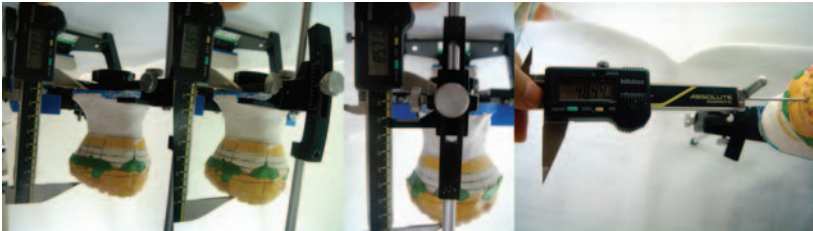


FIGURE 9-12 Before moving or sectioning the mounted casts, the vertical, anteroposterior, and mediolateral positions of the maxillary teeth must be recorded.

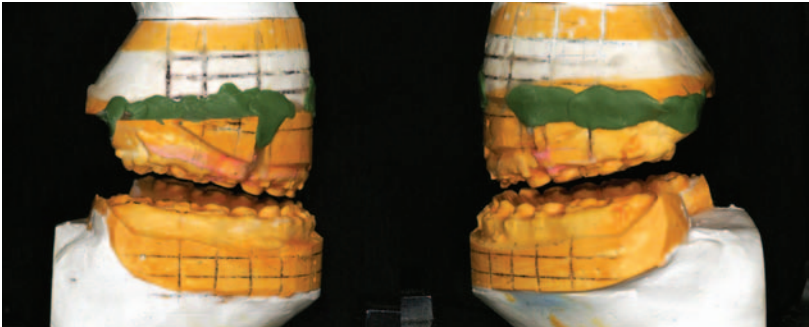


FIGURE 9-13 After the maxillary cast has been cut from the mounting ring, extraction space closure of the maxillary first premolar and distal-lateral rotation of the posterior segments in the three-piece maxilla are accomplished. The maxillary segments are repositioned according to the surgical treatment objective and held with wax and compound.

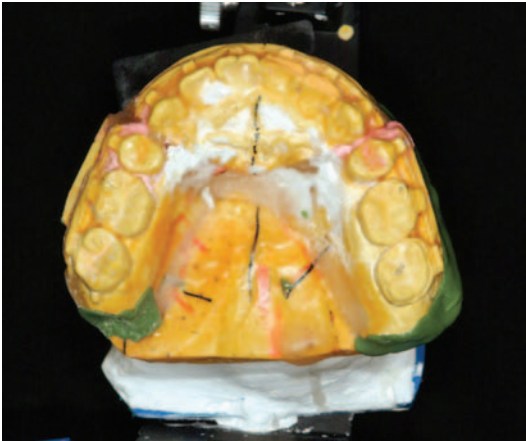


FIGURE 9-14 By taking an alginate impression and pouring new casts in dental stone, the repositioned and segmented maxillary cast is reproduced for the final wafer.

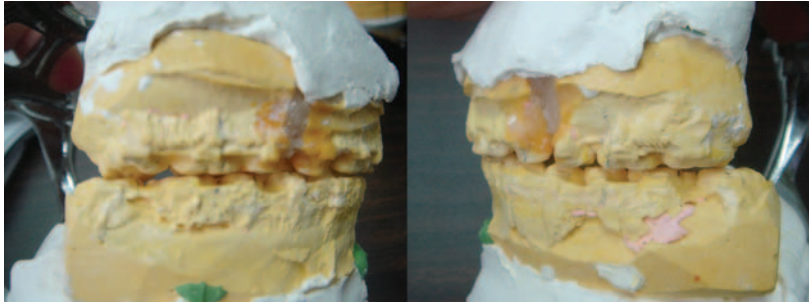


FIGURE 9-15 To construct the final wafer, the maxillary and mandibular casts are mounted in a hinge-type articulator in the final position of the jaws at surgery. The space for the final wafer between the maxillary and mandibular casts must be kept to a minimum so that the final wafer is as thin as possible.



FIGURE 9-16 After applying separating medium, a roll of quick-curing acrylic is adapted to the occlusal surface of the maxillary cast. Then the mandibular cast is positioned into the soft acrylic by closing the articulator. The cured final wafer is trimmed and polished. Because the maxilla will be segmented, two holes adjacent to each maxillary segment are needed.



FIGURE 9-17 The intermediate wafer (*white opaque*) is constructed under the final wafer (*clear*), which is fixed to the segmented maxillary cast. After the intermediate wafer is trimmed and polished, the lower surface of the final wafer should interdigitate easily into the upper surface of the intermediate wafer.

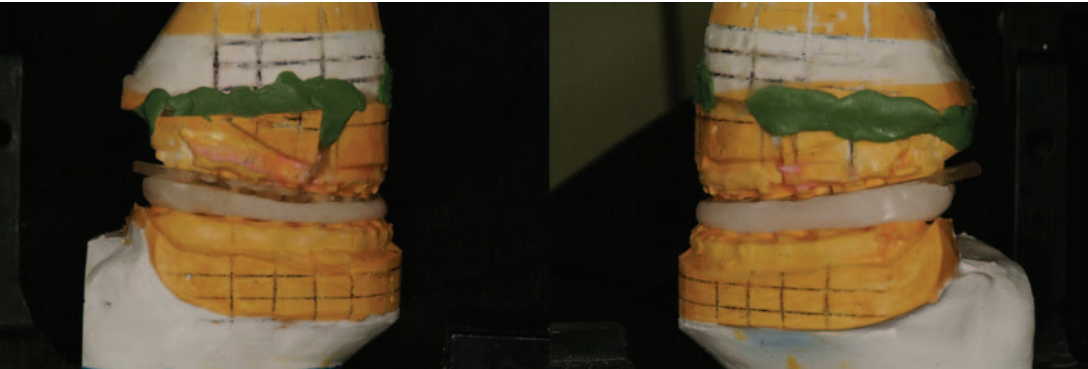


FIGURE 9-18 The combined final (*clear*) and intermediate (*white opaque*) wafers correspond to the jaw position following Le Fort I osteotomy, before completion of BSSRO.

casts can induce technical inaccuracy. It is hard to control the vertical, anteroposterior, and transverse movements of the segments simultaneously according to the STO, especially in a three-piece maxillary osteotomy case. Also, there are many chances to cause inaccurate simulation of surgical movements of the plaster casts. Fabrication of the surgical wafer may summate all of the errors of the previous stages.

Three-Dimensional VMS and Surgical Wafer Fabrication

Scanning of Models and Construction of Virtual Models

Three-dimensional virtual models were constructed using a laser scanning machine (Orapix system) and a three-dimensional software program (3-Dxer, KCI) (Figure 9-19).

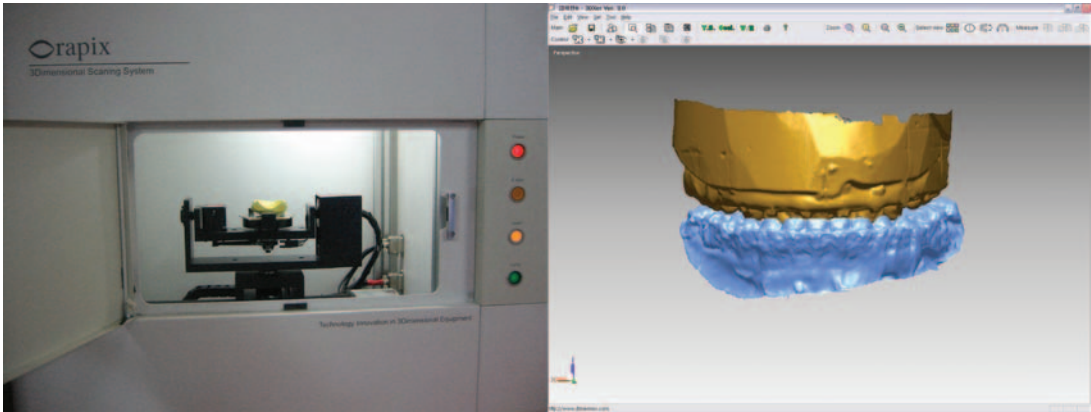


FIGURE 9-19 The laser scanning machine (Orapix system, KCI, Seoul, Korea) is used for scanning the model and the three-dimensional software program (3-Dxer, KCI) for constructing a three-dimensional virtual model.

Three-dimensional scanning is a type of reverse engineering, the original purposes of which were to reduce the period of development and cost, to establish standardization, and to increase the accuracy of products. Nowadays it is applied to the medical engineering area.

The basic concepts of the Orapix three-dimensional scanner are to shoot the laser light to the target material surface, to detect reflection, and to calculate its three-dimensional coordinate system using the trigonometric function (Figure 9-20). It has an accuracy level of ± 0.02 mm/10 mm and a resolution of $1,024 \times 768$ pixels.

Mounting of Virtual Models in the Virtual Articulator

The dental casts are mounted into the articulator using facebow transfer to reproduce the occlusion

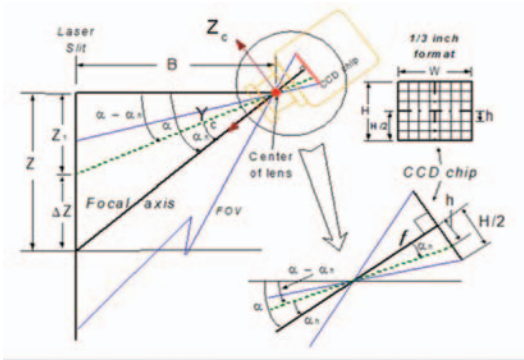


FIGURE 9-20 Basic concept of the Orapix three-dimensional laser scanner.

and jaw relationship of the patient. To transfer virtual data of the dental casts into the virtual articulator, three-dimensional positions of the mounted casts in relation to the articulator were analyzed using a dial height gauge (model 192-130 HW-30, Mitutoyo, Kanagawa, Japan) (Figure 9-21). The position of the dental casts was represented by three coordinate axes (X, Y, and Z axes). The X coordinate stood for the mediolateral position (right side of the vertical bar of the articulator: 0 mm), the Y coordinate for the vertical position (bottom of the lower member of the articulator: 0 mm), and the Z coordinate for the anteroposterior position (back side of the vertical bar of the articulator: 0 mm). We measured the vertical, anteroposterior, and mediolateral positions of the mesiobuccal cusp tip of the right and left first molars and the midpoint of the right central incisor edge of the maxillary and mandibular dental casts. By measuring the distance from the midpoint of the upper right central incisor tip and center point of the outside of the condylar elements of both sides to three-dimensional base lines, respectively, it is possible to relocate the virtual maxillomandibular dental casts in the virtual articulator. With these data and the three-dimensional VMS program (KCI), virtual models can be positioned in a virtual articulator (Figure 9-22). We planned a two-jaw surgery involving a three-piece Le Fort I osteotomy of the maxilla and setback of the mandible.



FIGURE 9-21 A Mitutoyo dial height gauge was used to measure the three-dimensional position of the dental casts.

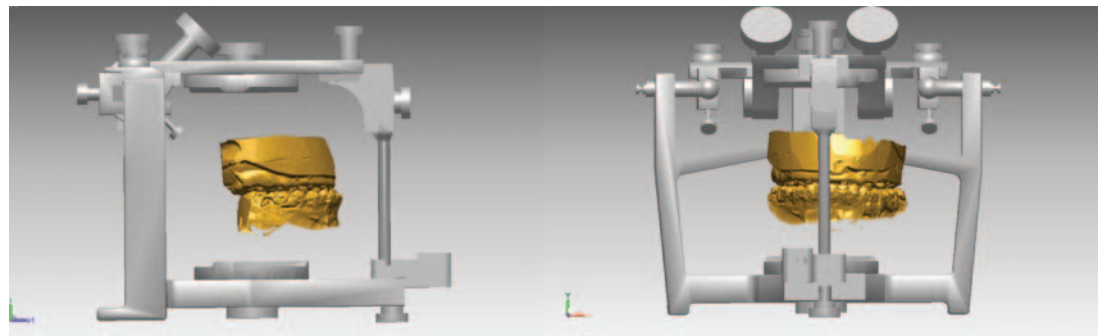


FIGURE 9-22 Mounting of the three-dimensional virtual models in the virtual articulator. From measurements of the mesiobuccal cusp tip of the right and left first molars and the midpoint of the right central incisor edge of the maxillary and mandibular dental casts, virtual models were positioned in the virtual articulator.

Three-Piece Le Fort I Osteotomy of the Maxilla

In three-dimensional spaces, three kinds of axis movement and axis rotation are possible. Therefore, these six kinds of freedom can produce all kinds of movements. The three-dimensional VMS program (KCI) adopts these functions and simulates various and precise surgical movements according to the STO.

The maxilla was segmented into three pieces to close the extraction space of the maxillary first premolars and to widen the posterior segments bilaterally for resolving the transverse deficiency of the maxilla (Figure 9-23). Anterior segmental osteotomy lines were established between the maxillary canine and the second premolar. Midsagittal osteotomy was done in the midpalatal area.

Closure of the extraction space of the maxillary first premolar was achieved by mesial

movement of the bilateral posterior segments (Figure 9-24). This movement was done along the maxillary occlusal plane.

To resolve the transverse deficiency of the maxilla, the posterior segments of the maxillary model should be widened bilaterally

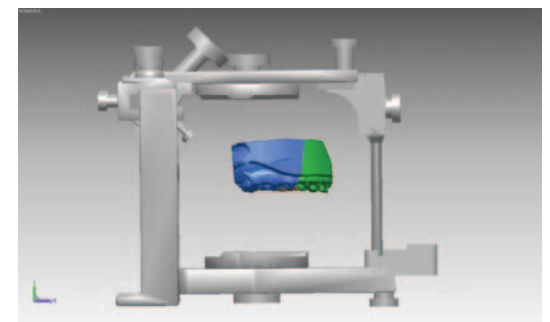


FIGURE 9-24 Bilateral posterior segments moved mesially to close the extraction space of the maxillary first premolar.

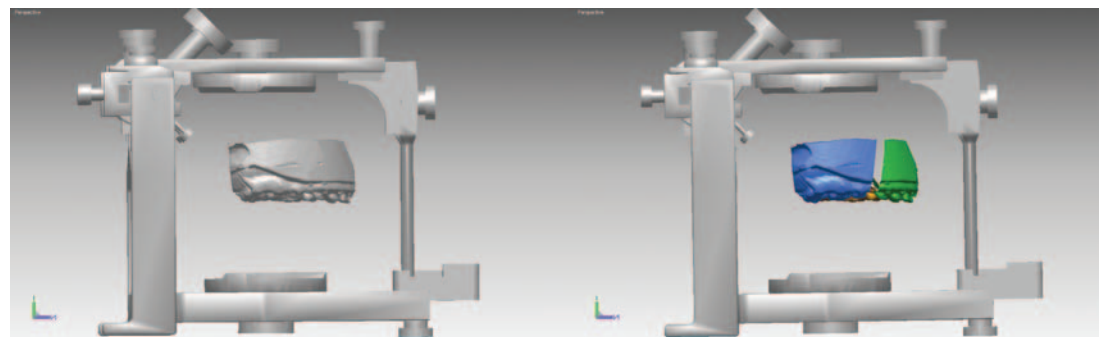


FIGURE 9-23 Three-piece Le Fort I osteotomy of the maxilla consisted of an anterior segmental osteotomy between the maxillary canine and second premolar and a midsagittal osteotomy in the midpalatal area.

(Figures 9-25 and 9-26). The blue mesh model indicates the mandibular model and the brown one implies the posterior segment of the maxillary model. The hinge axis point to rotate and widen the posterior segment of the maxillary model was a contact point between the maxillary canine and the second premolar. Using a track ball, the posterior segment was rotated distal-lateral around the hinge axis point until proper buccal overjet and stable cusp-fossa interdigitation were attained.

Spaces among the three segments indicate the result of distal-lateral rotation of the posterior segment for bilateral expansion in the maxilla (Figure 9-27). When compared with the initial

width and angulation of the posterior segment in the maxilla, bilateral expansion and distal-lateral rotation of posterior segments were effective in resolving the transverse deficiency of the maxilla (Figures 9-28 and 9-29). The segmented maxilla united into one piece for the next step.

Superior impaction of the posterior segment of the maxilla was planned to maximize the amount of mandibular setback and to normalize the angulation of the maxillary occlusal plane. The center of rotation was located at the bracket slot of the maxillary central incisor (Figure 9-30).

Superior repositioning of the posterior segment of the maxilla was established according

to the measurements from the STO (Figure 9-31). If the mesiobuccal cusp tip of the maxillary first molar was repositioned 1.5 mm upward, there would be a forward movement of point A of the maxilla owing to the location of the hinge axis point. This could help resolve the midface deficiency.

Superior repositioning of the posterior segment can bring inferior and posterior rotation of the maxillary anterior teeth. This caused occlusal interferences between the right maxillary lateral incisor, the right mandibular lateral incisor, and the canine (Figure 9-32). The green or blue areas represent occlusal interferences by the collision test.

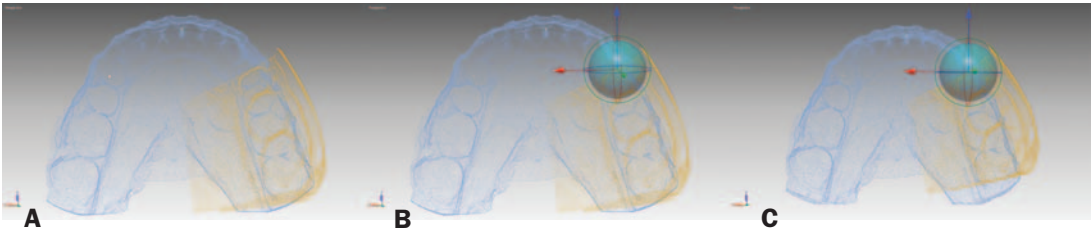


FIGURE 9-25 Location of the hinge axis point to rotate and widen the posterior segment of the left side. A, The blue mesh model indicates the mandibular model and the brown one implies the posterior segment of the maxillary model. The *green point* indicates the hinge axis point, which was a contact point between the maxillary canine and the second premolar. B, Before rotation. The *green sphere* represents the track ball to control movement and rotation of the selected object. C, After distal-lateral rotation of the posterior segment around the hinge axis point.

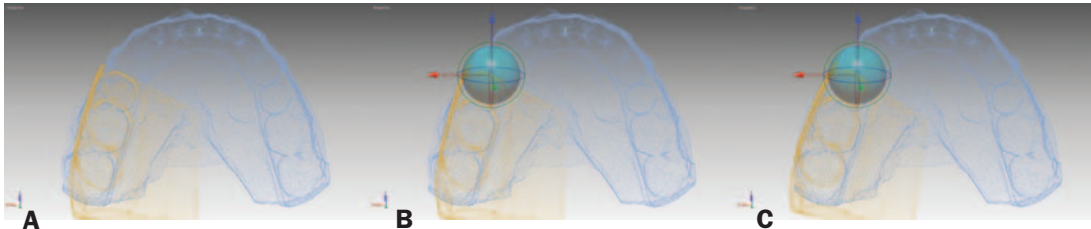


FIGURE 9-26 Location of the hinge axis point to rotate and widen the posterior segment of the right side. A, The *green point* indicates the hinge axis point, a contact point between the maxillary canine and the second premolar. B, Before rotation. The *green sphere* represents the track ball to control movement and rotation of the selected object. C, After distal-lateral rotation of the posterior segment around the hinge axis point.

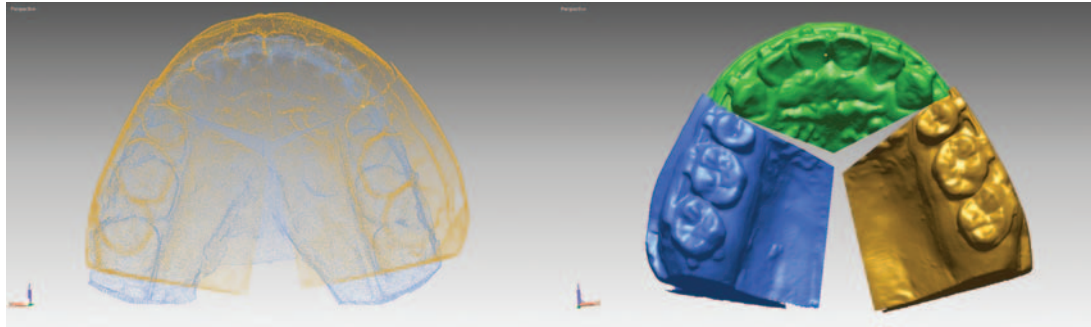


FIGURE 9-27 Superimposition of the maxillary casts between before and after extraction space closure and distal-lateral rotation of the posterior segments for bilateral expansion. Spaces among the three segments indicate the result of distal-lateral rotation and bilateral expansion of the posterior segment in the maxilla.

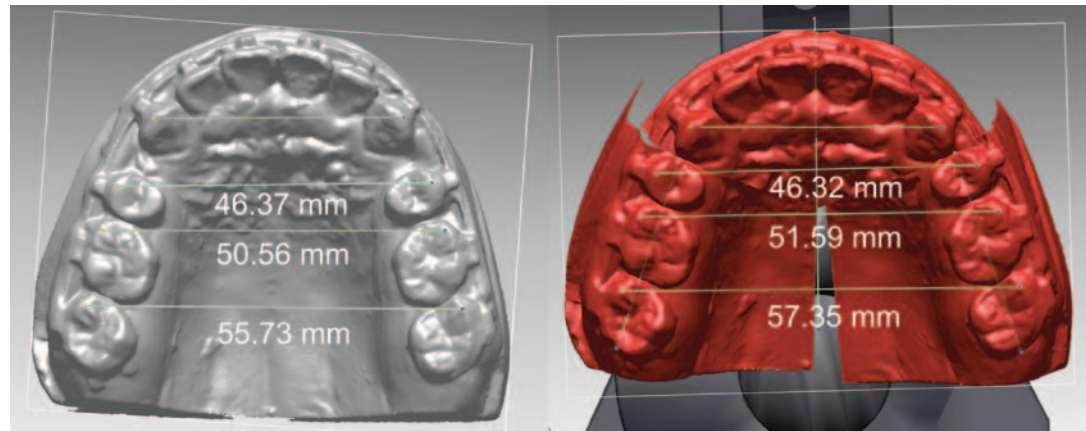


FIGURE 9-28 Increase in the inter-first molar width and inter-second molar width occurred from expansion of the posterior segment in the maxilla.

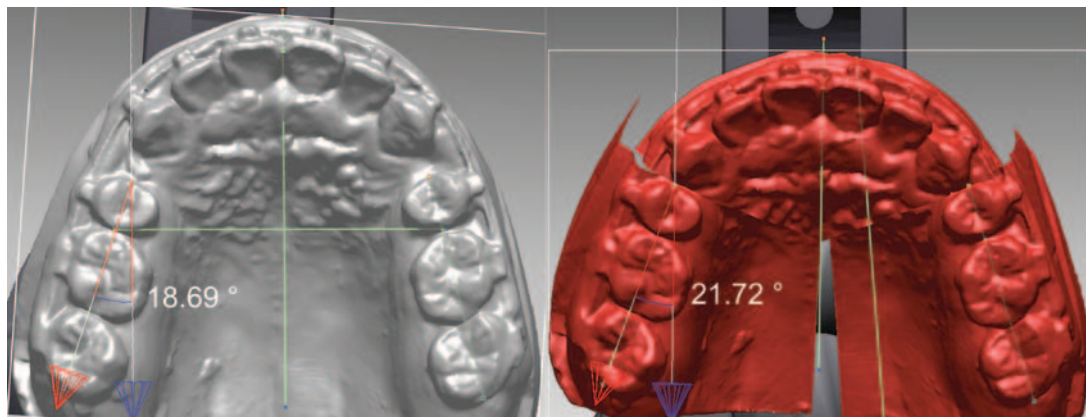


FIGURE 9-29 The distal-lateral rotation of the posterior segment in the maxilla resulted in an increase in the angulation of the posterior segment in relation to the midsagittal line.

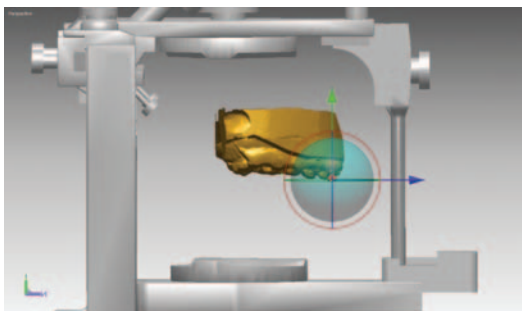


FIGURE 9-30 Location of the hinge axis point for superior impaction of the posterior segments of the maxilla was at the bracket slot of the maxillary central incisor. The *red point* indicates the hinge axis point, and the *green sphere* represents the track ball, which can control rotation.

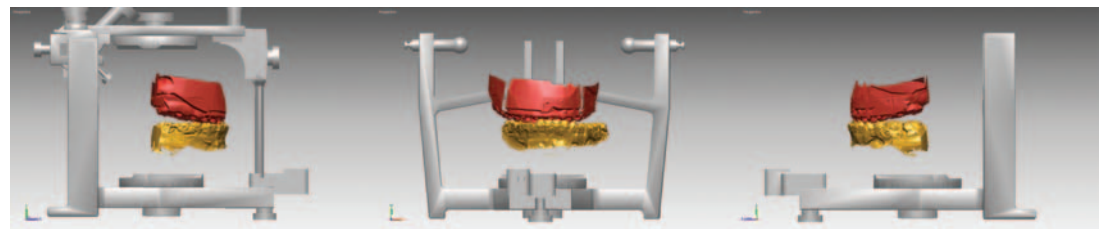


FIGURE 9-31 The mesiobuccal cusp tip of the maxillary first molar repositioned 1.5 mm upward.

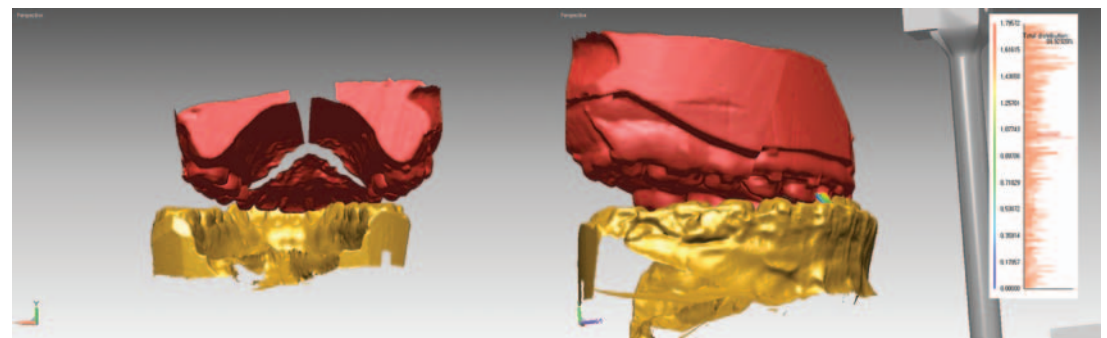


FIGURE 9-32 Occlusal interferences between the maxillary lateral incisor, the mandibular lateral incisor, and the canine of the right side occurred owing to the downward and backward rotation of the maxillary anterior teeth.

To eliminate the occlusal interferences, the upper member of the virtual articulator should be open and rotated upward using the hinge axis of the articulator (Figure 9-33). Compare the interocclusal distance between before and after bite opening. After getting adequate interocclusal distance, the intermediate surgical wafer can be made.

Fabrication of the Three-Dimensional Virtual Intermediate Wafer

After the repositioning of the maxilla, the steps for construction of the intermediate surgical wafer can be started. Basic data for the intermediate surgical wafer can be constructed by inserting an object between the maxillary and mandibular dentition (Figure 9-34) and getting an indentation of the occlusal surfaces of the maxillary and mandibular teeth (Figure 9-35). After cutting out the excess, the intermediate surgical wafer can be attained (Figure 9-36).

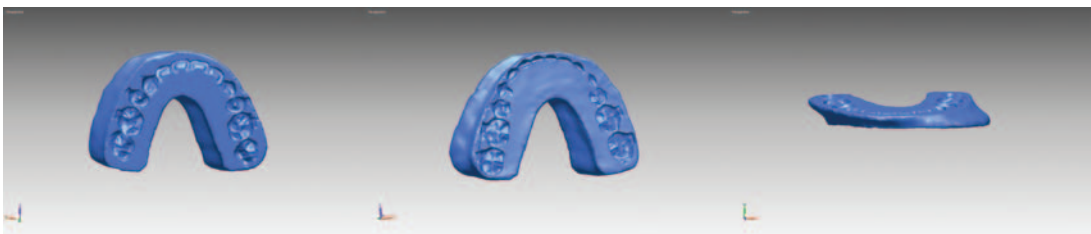


FIGURE 9-35 Indentations of the occlusal surfaces of the maxillary and mandibular teeth were attained.

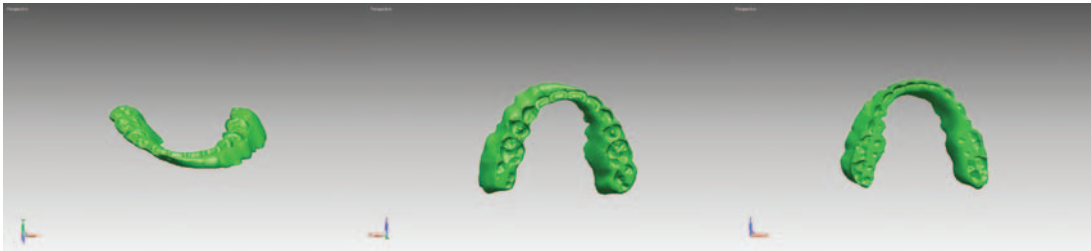


FIGURE 9-36 After cutting out the excess, a three-dimensional virtual intermediate surgical wafer has been fabricated.

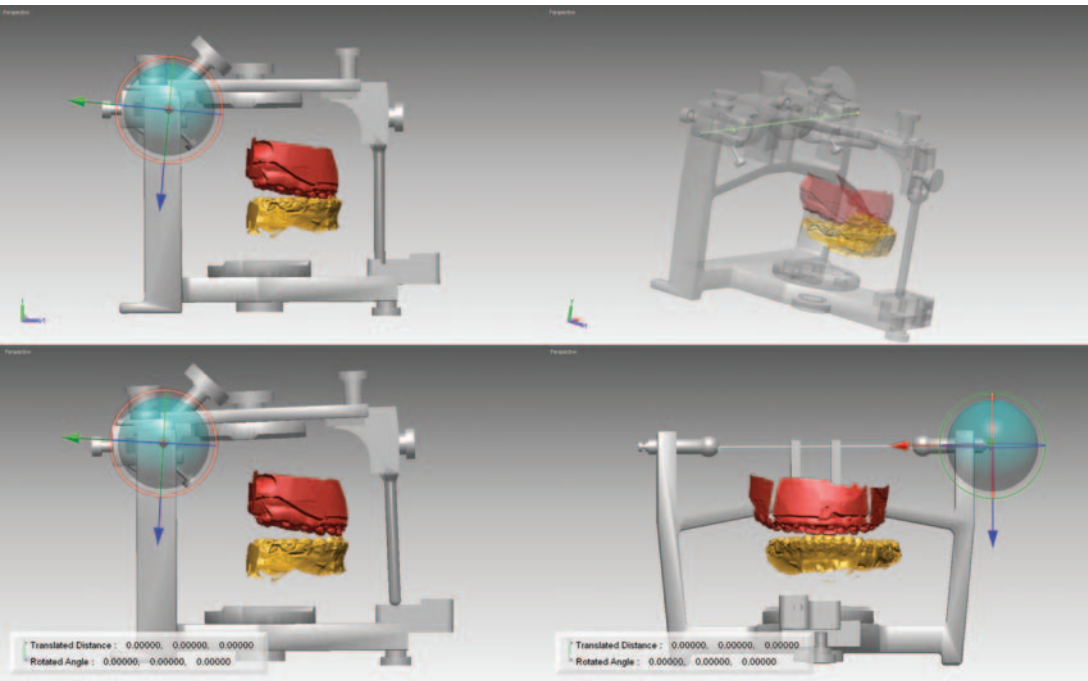


FIGURE 9-33 For elimination of the premature contact, the repositioned maxillary cast and the upper member of the virtual articulator should be open and rotated upward using the hinge axis of the articulator.

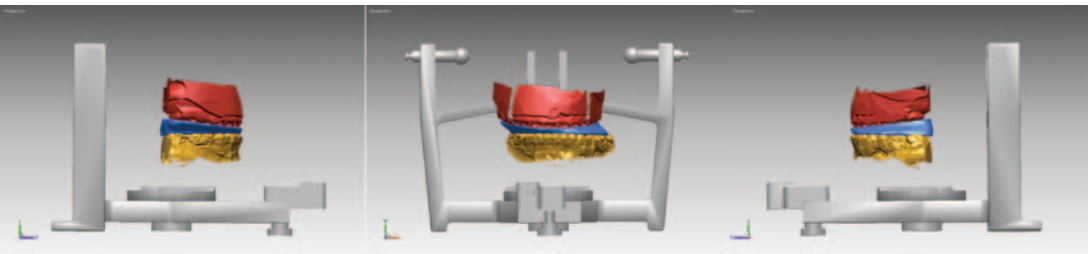


FIGURE 9-34 Basic data for the three-dimensional virtual intermediate surgical wafer were constructed by inserting an object between the maxillary and mandibular dentition.

Mandibular Setback

The criteria for the mandibular setback movement were overjet and overbite. We planned a 2.5 mm overbite and a 3.5 mm overjet (Figure 9-37). The mandible was set back along the mandibular occlusal plane. After setback of the mandible, bite opening of the posterior teeth was corrected by rotating the mandible using the hinge axis point of the mandibular central incisor tip. Eventually, the mandibular virtual model was repositioned to occlude the maxillary virtual one, simulating the final position of the jaws at surgery.

Anteroposterior and transverse position and rotation of the maxillary and mandibular virtual models were corrected (Figure 9-38). The green lines indicate the midline of the articulator and a connecting line between the mesiolingual cusp tip of the maxillary and mandibular first molars. These two lines intersect perpendicularly.

By contact test, even and simultaneous contact between the maxillary and mandibular dentition can be established (Figure 9-39). After repositioning of the maxilla and mandible, Class I canine and Class II molar relationships were established. There was normalization of the overbite and overjet relationships in the anterior and posterior teeth and the occlusal plane angulation (Figure 9-40).

Fabrication of the Three-Dimensional Virtual Final Wafer

After repositioning of the mandible is completed, the steps for attaining a final surgical wafer can be started. Basic data for final surgical wafer can be constructed by inserting an object between

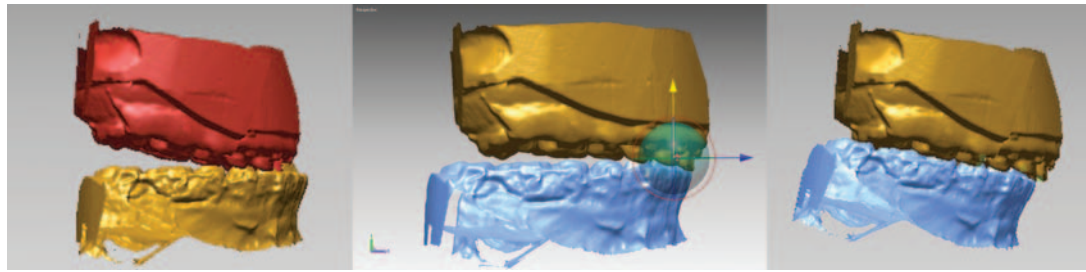


FIGURE 9-37 The mandible was set back along with the mandibular occlusal plane until normal overbite and overjet were established. After setback of the mandible, bite opening of the posterior teeth was corrected by rotation of the mandible using the hinge axis point of the mandibular central incisor tip.

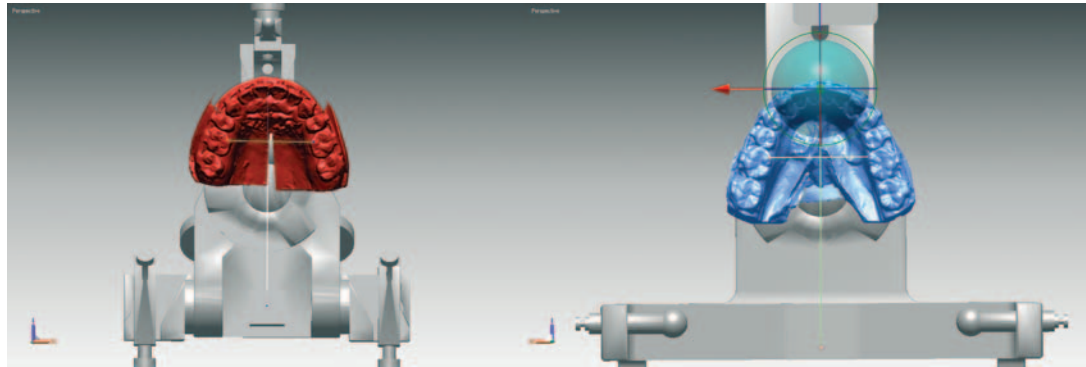


FIGURE 9-38 Correction of the anteroposterior and transverse positions and rotation of the maxilla and mandible.

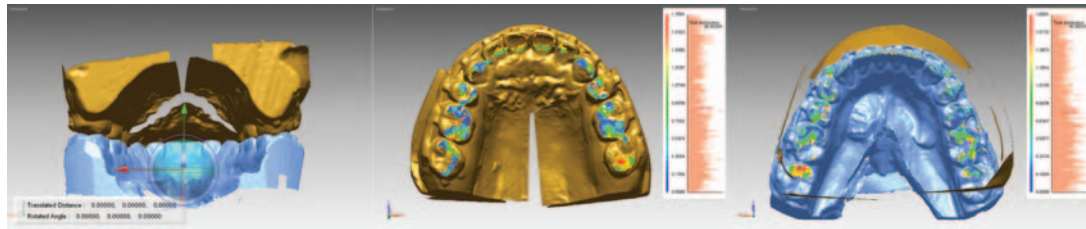


FIGURE 9-39 Even and simultaneous contact between the maxillary and mandibular dentition was established by adjusting the track ball in the mandible. The *red* stands for no contact, and the *blue* shows the presence of a contact.

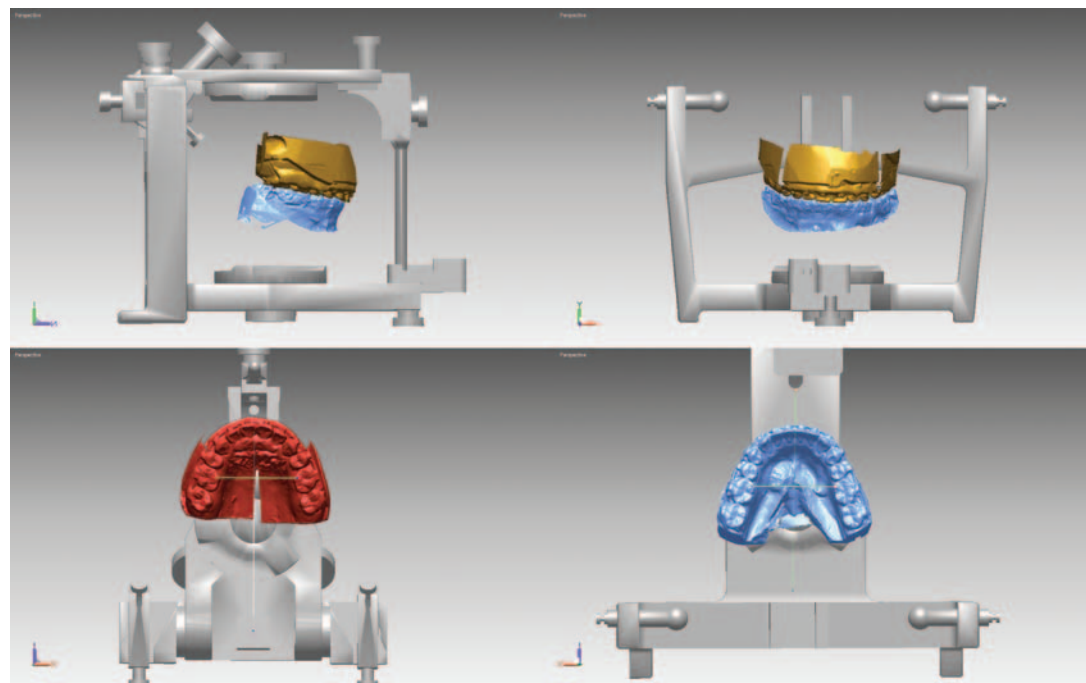


FIGURE 9-40 Final position of the maxilla and mandible. At this stage, the final surgical wafer for surgery can be constructed.

the maxillary and mandibular dentition (Figure 9-41) and creating indentations of the occlusal surface of the maxillary and mandibular teeth (Figure 9-42). After removing the excess, the final surgical wafer is constructed (Figure 9-43).

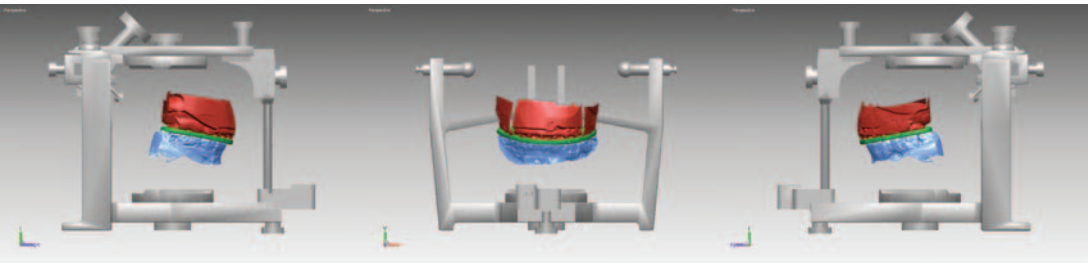


FIGURE 9-41 Basic data for the three-dimensional virtual final surgical wafer were constructed by inserting the object between the maxillary and mandibular dentition.



FIGURE 9-42 Indentations of the occlusal surfaces of the maxillary and mandibular teeth were attained.

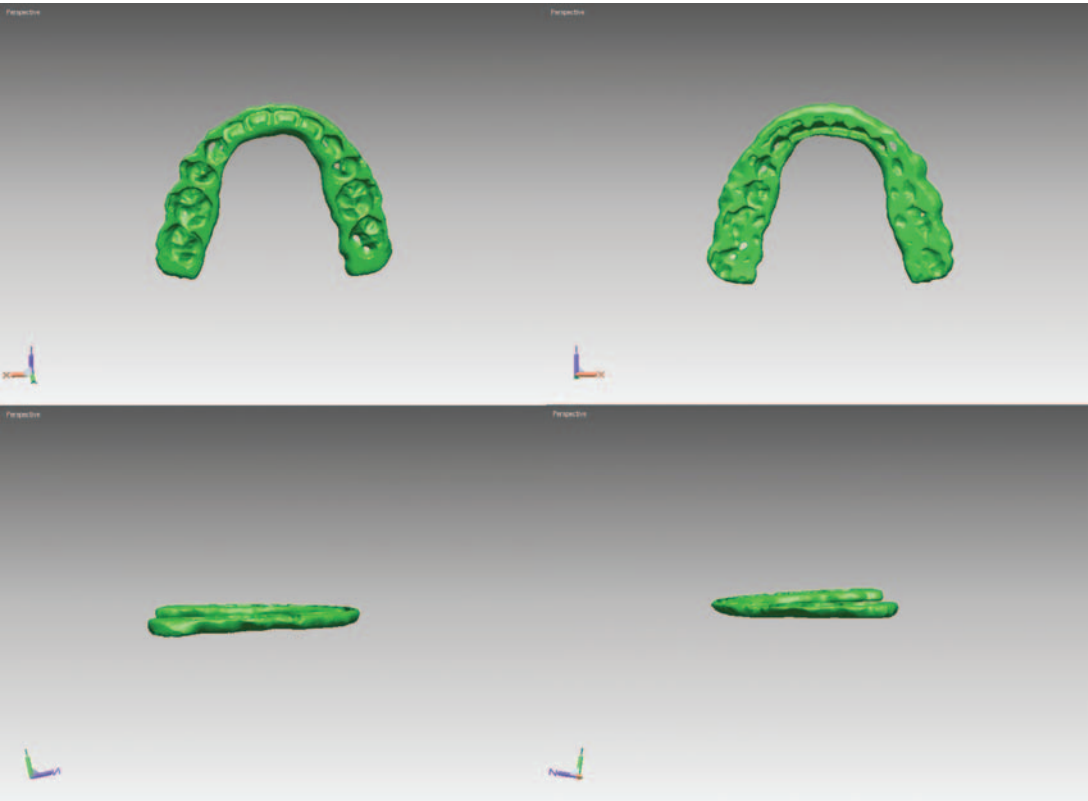


FIGURE 9-43 After cutting out the excess, a three-dimensional virtual final surgical wafer was constructed.

Fabrication of the Maxillary and Mandibular Dental Arches and Wafers Using the Stereolithographic Technique

For construction of the intermediate (Figure 9-44) and final surgical wafers (Figure 9-45)

from three-dimensional virtual data, the stereolithographic technique (Viper Si2, Viper SLA system, 3-D Systems Corporation, Valencia, CA) was used. Its accuracy was 100 mm ± 20 µm. To check its accuracy, resin models for the maxillary and mandibular dental arches were also made (Figure 9-46). The intermediate (Figure 9-47) and final wafers (Figure 9-48) were fitted accurately with the maxillary and mandibular resin models. During surgery, the final wafer fit well into the maxillary and mandibular dentition (Figure 9-49).

Superimposition of Three-Dimensional Virtual Models between Pre- and Post-Virtual Model Surgery

In the maxilla, there was a forward movement of the posterior segment, superior repositioning and rotation of the maxilla, advancement of the point A area, and inferior- and posterior rotation of the maxillary incisors (Figure 9-50). In the mandible, there was posterior repositioning with rotation of the mandible when closing the bite opening in the posterior teeth (Figure 9-51). Rotation and mid-line deviations of the maxillary and mandibular dental arches were corrected.

Result of Surgery

Postoperative 3-month data are as follows: facial (Figure 9-52) and intraoral photographs (Figure 9-53), a lateral cephalogram (Figure 9-54, Table 9-2), and a posteroanterior cephalogram (Figure 9-55).

Superimposition of lateral cephalogram tracings of the STO and the actual result of surgery shows that the superior repositioning of the posterior segments of the maxilla was under-corrected compared with the STO (Figure 9-56). It seems that the posterior repositioning still needs more careful surgical manipulation.

Superimposition of the maxillary virtual models between post-virtual model surgery and the actual result of surgery shows that there is good accordance and that the vertical height difference in the upper central incisor and first molar is minimal (Figure 9-57).

The distance and angle in the posterior segment of the maxillary virtual models between post-virtual model surgery and the actual result of surgery are almost the same (Figures 9-58 and 9-59).

Conclusion

Indications for three-dimensional VMS include: two-jaw surgery including two- or three-piece maxillary osteotomy, facial asymmetry correction, and vertical discrepancy correction.

Three-dimensional VMS has certain advantages.



FIGURE 9-44 The intermediate wafer was made from photoactive resin from the three-dimensional virtual data.



FIGURE 9-45 The final wafer was constructed from photoactive resin from the three-dimensional virtual data.



FIGURE 9-46 The maxillary and mandibular dental arches were constructed from photoactive resin from the three-dimensional virtual data.



FIGURE 9-48 The final wafer fits well into the maxillary and mandibular resin models.



FIGURE 9-47 The intermediate wafer matches accurately with the maxillary and mandibular resin models.

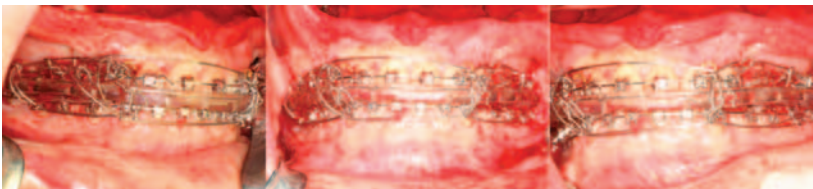


FIGURE 9-49 In surgery, the final wafer fits well into the maxillary and mandibular dentition.

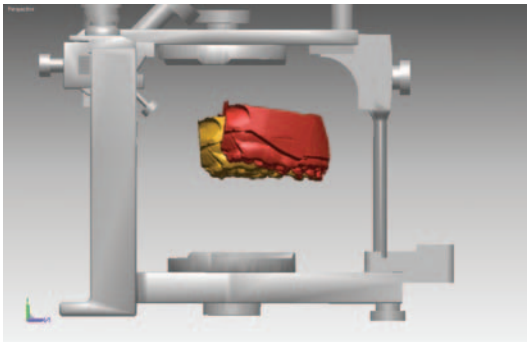


FIGURE 9-50 Superimposition of the maxillary virtual models between pre- and post-virtual model surgery.



FIGURE 9-51 Superimposition of the mandibular virtual models between pre- and post-virtual model surgery.



FIGURE 9-52 Postoperative 3-month facial photographs. The concave profile and facial asymmetry to the right side are corrected. However, some swelling of the nose and upper lip remains.



FIGURE 9-53 Postoperative 3-month intraoral photographs. Extraction spaces of the upper first premolars are closed. Class II molar and Class I canine relationships are established. Normal overbite and overjet were achieved in the anterior and posterior teeth. The lower dental midline is slightly overcorrected to the left side.



FIGURE 9-54 Postoperative 3-month lateral cephalogram. There is normalization of the skeletal discrepancies in the sagittal and vertical relationship between the maxilla and the mandible.

Table 9-2 Measurement of 3-Month Postoperative Variables in the Lateral Cephalogram		
Measurement	Preoperative	Postoperative
SNA (°)	83.84	82.25
SNB (°)	86.26	80.70
ANB (°)	-2.42	1.55
A-N perp (mm)	7.42	4.35
Pog-N perp (mm)	20.32	3.52
APDI (°)	99.59	88.48
ODI (°)	56.77	62.24
FMA (°)	19.01	26.74
Facial height ratio (%)	69.92	64.80
Ramus height (mm)	68.63	58.47
Mandibular body length (mm)	87.23	84.97
Body to ACB ratio	1.23	1.18
U1 to FH (°)	123.75	122.06
IMPA (°)	89.94	94.22
Interincisal angle (°)	127.3	116.98
Nasolabial angle (°)	64.93	84.29

ACB = anterior cranial base; APDI = anteroposterior displasia; FH = Frankfort horizontal; FMA = Frankfort mandibular plane angle; IMPA = incisor mandibular plane angle; ODI = overbite depth indicator; U1 = upper incisor.



FIGURE 9-55 Postoperative 3-month posteroanterior cephalogram. Facial asymmetry to the right side is corrected according to the surgical treatment objective.

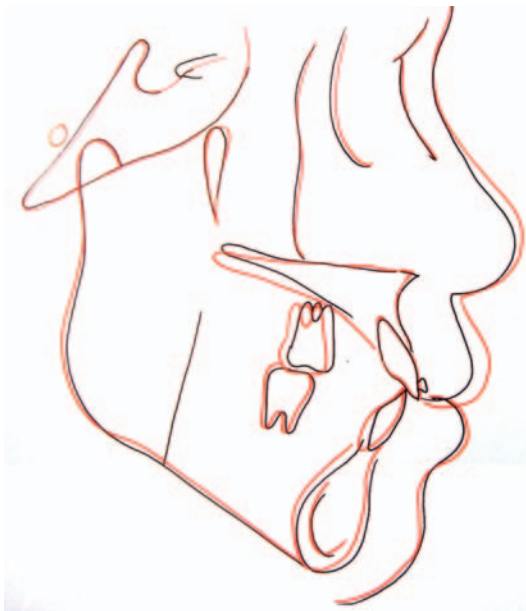


FIGURE 9-56 Superimposition of the lateral cephalogram tracings of the surgical treatment objective (STO) and the actual result of surgery. The *black line* stands for the STO and the *red one* for actual postoperative tracing.

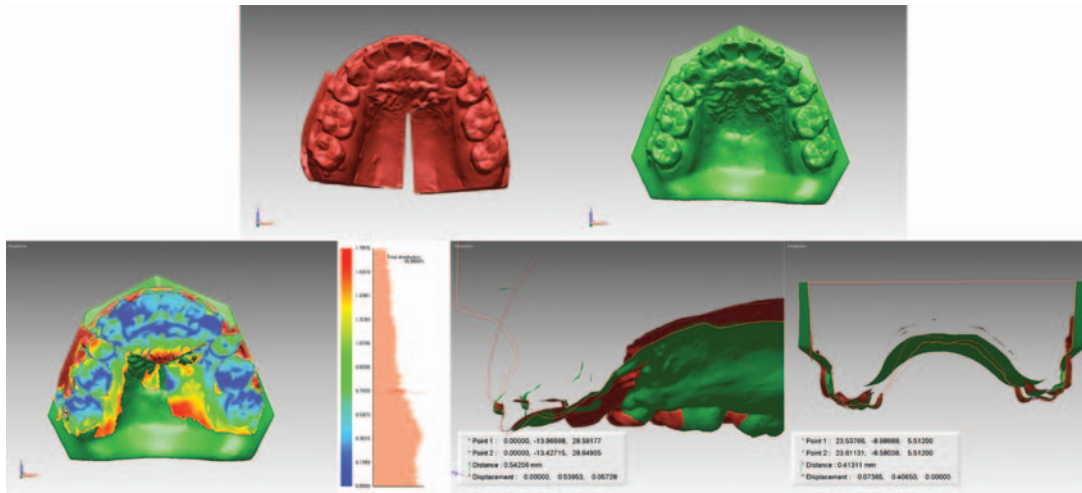


FIGURE 9-57 Superimposition of the maxillary virtual models between post-virtual model surgery and the actual result of surgery. The *blue* means good accordance between post-virtual model surgery and the actual result of surgery. Vertical height differences in the upper first molar and in the upper central incisor are 0.4 mm and 0.5 mm, respectively.

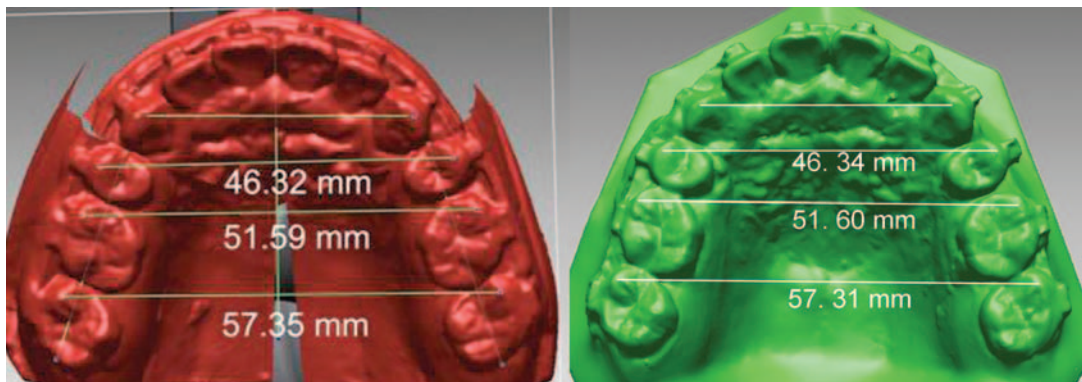


FIGURE 9-58 Comparison of distance in the posterior segment of the maxillary virtual models between post-virtual model surgery and the actual result of surgery.

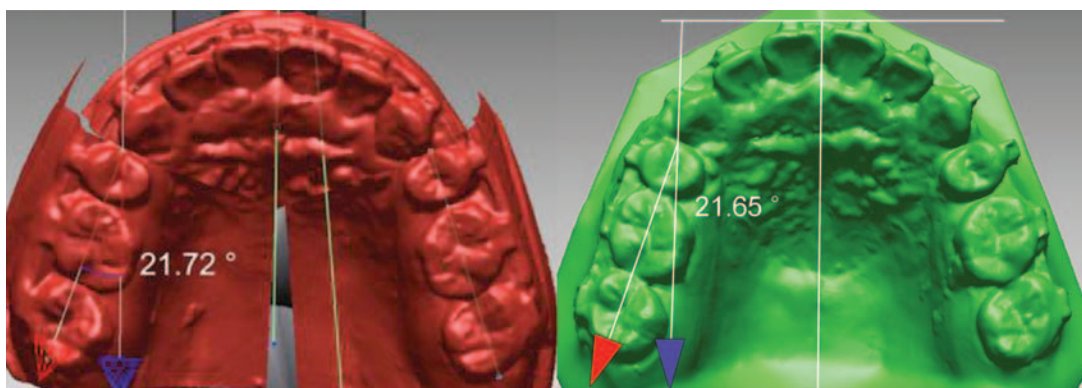


FIGURE 9-59 Comparison of angle in the posterior segment of the maxillary virtual models between post-virtual model surgery and the actual result of surgery.

1. It can improve the accuracy of the model surgery with elimination of the sectioning of plaster casts.
2. It is easy to control the three-dimensional movements of the segments simultaneously according to the STO.
3. It can be used as a decision-supporting tool to compose several surgical options by reducing the burden of a lengthy and laborious work process and reducing time loss associated with MMS.
4. Accurate and precise simulation of surgical movements can minimize errors during fabrication of the surgical wafers.
5. It can be used in a multicenter study because objective and measurable evaluation is possible.
6. It can be an educational tool for those who are involved in the orthognathic surgery field, such as orthodontists, oromaxillofacial surgeons, residents, and dental students.

Until now, three-dimensional CT data have not been able to reproduce the occlusal surfaces of the teeth owing to limitations of the slice thickness. Although, an accurate surgical wafer cannot be fabricated using three-dimensional CT data alone. However, improvements in three-dimensional CT technology will provide a breakthrough for combining data from the three-dimensional virtual models and three-dimensional CT.^{25,26} In addition, soft tissue change can also be predicted using these combined methods. Additionally, recent developments in three-dimensional CT/magnetic resonance imaging and three-dimensional CAD/CAM technology will enable embodiment in the three-dimensional VMS area and surgical navigation system in the near and promising future. The evolution of predictable three-dimensional virtual model surgery and surgical wafer fabrication will greatly reduce laboratory time spent involved with model surgery – it will ultimately be done quickly and precisely by specially trained skillful laboratory technicians under the supervision of an oral and maxillofacial surgeon. The goal of our present studies relates to reducing time spent with intended three-dimensional model surgery and achieving more predictable and stable repositioning of the jaws by orthognathic surgery.

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Surgical Planning for Distraction Osteogenesis

Jaime Gateno, John F. Teichgraeber and James J. Xia

Distraction osteogenesis has revolutionized craniofacial surgery. However, planning protocols for distraction osteogenesis are still in their rudimentary stages. Some authors have suggested that detailed presurgical planning is unnecessary with distraction osteogenesis, because “you can adjust as you go.”¹ A number of surgeons, frustrated by a series of bad outcomes, have used the technique of “callus manipulation.” This technique involves the initial distraction of the bone segments in a preplanned direction. At the completion of distraction, the distraction device is removed prior to callus consolidation. At this stage, the callus is manipulated, either manually or with the help of elastic bands, to produce the final occlusion.² The authors believe that accurate planning for distraction is not only possible but also advisable.

Orthognathic surgery and distraction osteogenesis have three steps in common. Both techniques require osteotomies, mobilization of the segments, and a period of stabilization. The only difference between these two techniques is that, in distraction, the bone segments are slowly moved over time to their final position, whereas in conventional surgery, this movement is immediate and it is accomplished intraoperatively. The success of distraction osteogenesis depends on understanding the path that the segments must take to arrive at their final position. Having determined the ideal path for distraction, the surgeon then selects the appropriate distraction device and formulates a recipe to achieve the desired outcome.

The authors have developed a system to plan distraction osteogenesis that is as reliable as the current methods used to plan orthognathic surgery.³⁻⁵ The purpose of this chapter is to present this planning process and discuss its use in distraction of the mandible, maxilla, and midface.

Planning for Mandibular Distraction

Indications

Distraction osteogenesis has been used to treat patients with different types of mandibular

deformities. These patients can be classified into three groups. The first group consists of infants and young children with micrognathia, severe enough to cause obstructive sleep apnea.⁶⁻⁸ Patients with hemifacial microsomia make up the second group.^{5,9} The final group consists of adolescent and adult patients with dentofacial deformities, in which distraction has been used in place of orthognathic surgery.

Currently, the most commonly accepted indication for mandibular distraction is the treatment of infants and children with severe mandibular hypoplasia. The majority of these patients have Treacher Collins syndrome, Nager syndrome, or Pierre Robin sequence. Most of these patients require a tracheostomy to maintain their airway. Unfortunately, long-term tracheostomies are associated with a high rate of complications, including death.^{10,11} Prior to distraction, the treatment alternatives in these patients included ramus osteotomies with interpositional bone grafts or costochondral grafts.¹² Because of the difficulty in obtaining bone grafts, most authors delayed surgery in these patients until 6 years of age. Distraction osteogenesis facilitates the early treatment of these patients by allowing significant lengthening of the mandible without the need for bone grafts.⁷

Distraction has been used in place of tracheostomy to manage the airway in patients with severe Pierre Robin sequence who have failed nonsurgical maneuvers.⁷ However, many of these patients have normal growth potential and will exhibit remarkable catch-up growth without the need for surgical intervention. In these patients, the tracheostomy is usually needed for less than a year.¹³ Since the long-term consequences of distraction are unknown, surgeons should carefully consider the options.

The treatment of patients with hemifacial microsomia has always been controversial, and the advent of distraction has added to the confusion. Historically, there are two approaches. The rationale for these two different approaches is based on conflicting studies regarding the progression of the deformity. One approach

recommends early intervention to prevent the progression of the mandibular and maxillary deformity.¹⁴ It is based on the premise that the deformity, if left untreated, worsens over time. The second approach delays intervention until the completion of growth. It is based on the premise that the deformity, if left untreated, remains stable over time.^{15,16}

The severity of hemifacial microsomia varies widely. It dictates the timing and the treatment plan for patients with the deformity. Pruzansky, and Kaban and colleagues have classified the mandibular deformity based on its severity, and their schemes are useful in treatment planning.^{14,17} Patients with the mildest deformity (Type I) have a decrease in the size of the involved ramus and condyle. The shape of these structures is grossly normal (ie, hypoplasia, without marked dysmorphism). In these patients, the condyle is centered in the glenoid fossa, and joint function is normal. In Type II patients, the involved ramus and condyle are small and deformed (ie, hypoplasia and dysmorphism). This group can be further divided into two subgroups depending upon the relationship between the condyle and glenoid fossa. In Type IIA patients, the condyle is centered in the glenoid fossa, whereas in Type IIB patients, the condyle is usually displaced anteriorly, medially, and inferiorly. Type IIA patients usually have normal joint function, which is lacking in Type IIB patients. Finally, patients with the most severe deformity (Type III) have agenesis of either the involved condylar process or the entire ramus.

Patient selection in hemifacial microsomia is critical for the success of distraction osteogenesis. In Type I patients, the authors do not use distraction as their primary mode of therapy. Since these patients usually respond to functional therapy, it is used as the primary mode of treatment. In patients with mild deformities, the authors often recommend waiting until completion of growth prior to intervention. In these patients, the treatment of choice is usually orthognathic surgery, with additional onlay grafts, if necessary.

The authors have used distraction osteogenesis in Type II patients, with mixed results. In Type IIA patients, distraction has been used to lengthen the mandible on the involved side. With this technique, it is possible to correct the chin deviation and the canting of the mandibular occlusal plane. The authors have not been able to achieve facial symmetry, especially in the gonial region. This is not surprising, since it is geometrically impossible to produce mandibular symmetry by performing a single unilateral osteotomy.

In Type IIB patients, the authors have used the multiplanar distractor device to attempt to reposition the condyle in the glenoid fossa. This type of movement requires angular distraction to torque the condyle backwards and outwards, as it is distracted linearly in a superior direction. To date, this technique of distraction has been unsuccessful. The failure of this approach was addressed in a biomechanical study by the authors.¹⁸ The study demonstrated that tissue resistance to angular distraction is higher than the torque resistance of the multiplanar pins currently on the market.

Type III patients with complete agenesis of the ramus are usually not candidates for distraction unless the ramus and condyle have been previously constructed with costochondral grafts. Distraction of the costochondral grafts is possible, but the graft should be of sufficient volume for it to be successful.¹⁹

A number of surgeons have used distraction osteogenesis in place of orthognathic surgery for the correction of common dentofacial deformities. Currently, the authors still favor sagittal osteotomies over distraction in these patients.

A sagittal split osteotomy can be used to lengthen the mandible without the use of bone grafts. Moreover, it can be done intraorally, thus avoiding external scars, and the occlusion can be precisely set. This procedure can usually be completed in less than 3 hours. In the authors' opinions, distraction should be reserved for those occasional patients who require very large advancements. Guerrero and colleagues have successfully used distraction to increase the width of the anterior mandible.²⁰ Although the authors have no personal experience with this innovative technique, it appears to be technically sound.

Planning

When the authors first employed distraction osteogenesis in 1996, the protocols for treatment planning were limited. It was clear that going to the operating room without having a plan was risky. The possibilities for unexpected outcomes were high. Therefore, the authors employed a treatment planning process similar to the one used for orthognathic surgery. However, the use of acetate drawings and dental models was inadequate to solve the complex three-dimensional problems involved in mandibular distraction. It became obvious that the only way to solve this complex problem was to use three-dimensional computer modeling. Over the ensuing years, the authors developed a computerized system that allowed for accurate three-dimensional planning.

The first step in this planning system involves creating a computerized three-dimensional model of the facial skeleton. This model is constructed from a computed tomography (CT) scan of the patient's maxillofacial region. After the model

has been created, it is imported into a computer program, which enables visualization and manipulation of the facial skeleton in three dimensions (Figure 10-1).

Initially, the facial skeleton is oriented in a unique three-dimensional coordinate system. The osteotomies are performed, separating the mandible into proximal and distal segments. Subsequently, the authors create an animation that simulates the distraction process. This animation is similar to the traditional animation used in cartoons, in which a series of still images (frames) are displayed sequentially to produce the illusion of motion. Using special software, it is only necessary to create the initial and final frames. This software creates all the necessary intermediate frames. The first frame shows the mandible in its preoperative condition, and the last frame shows the desired distraction outcome. To create the last frame, the proximal and distal segments are mobilized to the desired final position.

In bilateral cases, two osteotomies are performed, separating the mandible into one distal and two proximal segments. The distal segment is placed in maximal intercuspation, and the proximal segments are moved until the condyles are centered in the glenoid fossae. In unilateral cases (eg, hemifacial microsomia), the distal segment is rotated around the uninvolved condyle until the chin and mandibular dental midlines are aligned with the sagittal plane. The proximal segment is moved until the condyle is centered in the glenoid fossa.

After the animation sequence has been created, it can be visualized from multiple angles. Analysis of this sequence demonstrates the type of movements that are necessary to achieve the desired outcome (Figure 10-2). This step is

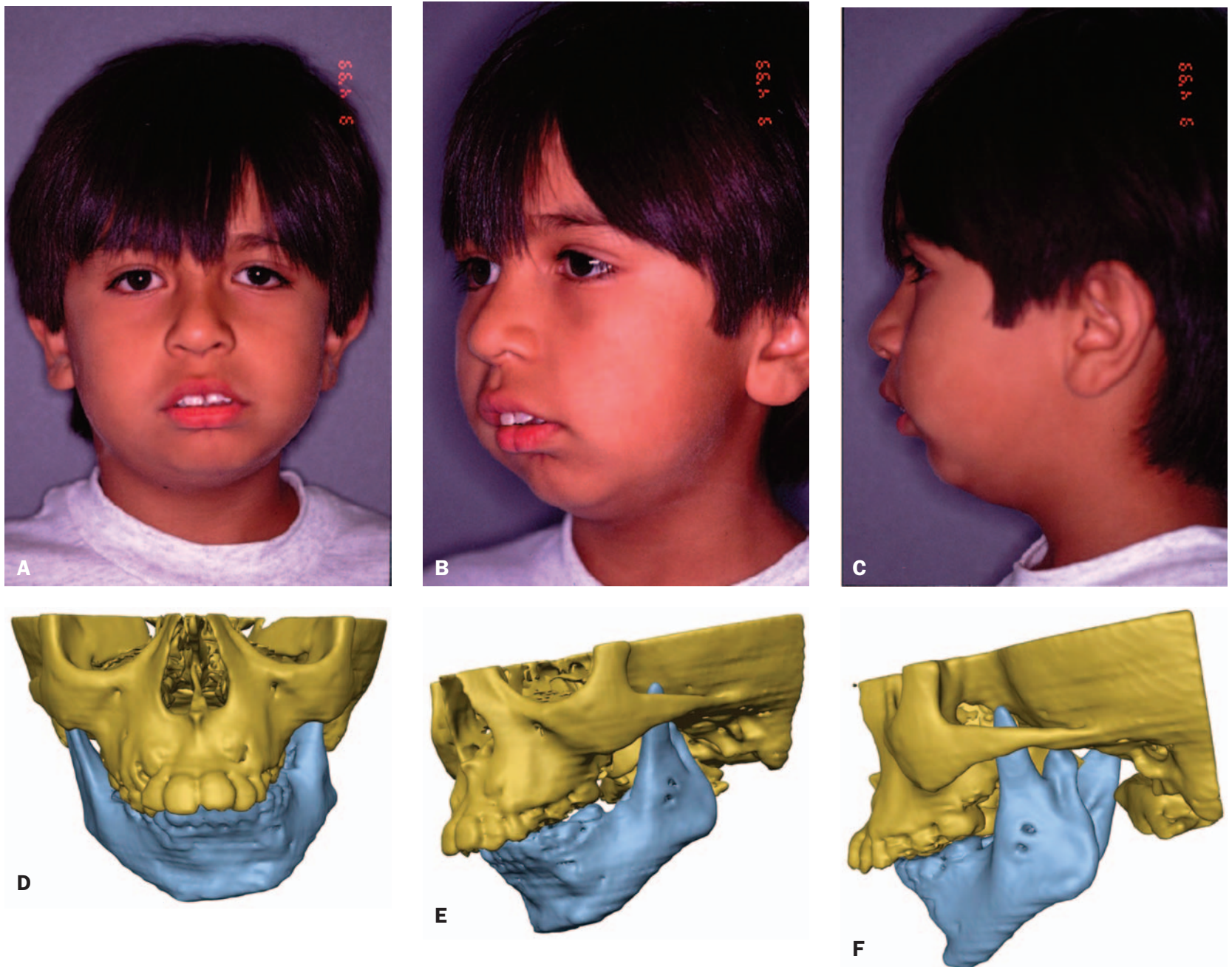


FIGURE 10-1 A, B, C, Nine-year-old patient with Type IIB hemifacial microsomia involving the left side of the face. D, E, F, The reconstructed three-dimensional computed tomography scan of the facial skeleton.

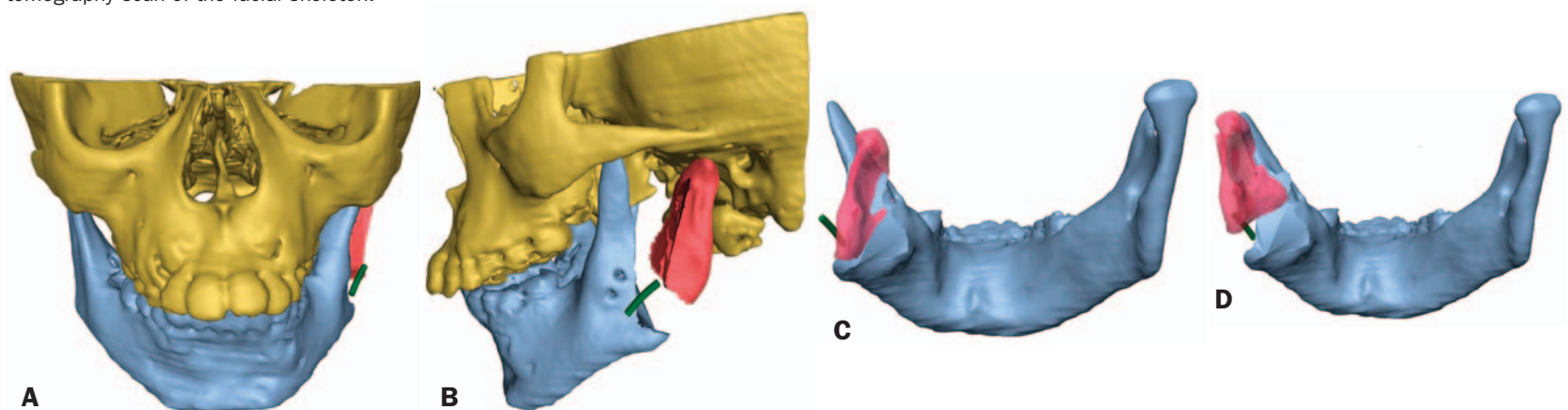


FIGURE 10-2 An osteotomy of the left ramus is completed and distraction is simulated (A, B). The proximal segment is moved and the condyle is centered in the glenoid fossa (B, D). The distal segment is rotated around the right condyle to move the chin to the midline and level the mandibular occlusal plane (B, D). A curvilinear distraction path (in green) is necessary to achieve this movement (A, B, C, D). In this patient, the authors selected a multiplanar device for distraction, which is the only one capable of producing this type of movement.

necessary to select the appropriate type of distractor. The selection of a particular type of device should be based on the ability of that device to perform the necessary spatial movements.

Once the decision to use a particular distractor has been made, a virtual model of the distractor is created and installed. When the external multi-planar device is used, the virtual distractor is pre-bent around the A joint until the angle between the distractor's arms mirrors the patient's gonial angle. This pre-bending allows the distractor's arms to be oriented parallel to the mandibular plane and the posterior border of the ramus. After the distractor has been pre-bent, it is positioned parallel to the sagittal plane at an average distance of 30 mm from the lateral surface of the mandible (Figure 10-3A).

Once the distractor is installed, the process of distraction is again simulated. Finally, the computer software formulates the linear and angular changes for each of the distractor components needed to achieve the desired outcome. This establishes the recipe necessary to activate the device during the distraction process (Figure 10-3B).

Transfer of the Surgical Plan to the Patient

The success of a planning process depends on the surgeon's ability to execute the plan at the time of surgery. As a result, the authors developed a technique that enables them to precisely install the distractor as indicated in the presurgical plan. To accomplish this, it is necessary to transfer information regarding pin position, pin orientation, and pin length from the computer model to the patient. Pin position is defined as the pin's point of entry in the mandible; pin orientation is defined as the orientation of the pins in space; and pin length is defined as the distance from the distractor to the mandible. The transfer of information regarding pin position and orientation from the computer model to the patient is accomplished by creating a surgical template. This template is designed in the computer by creating a "box-object" that is positioned to encompass the pins and the angle of the mandible (Figure 10-3C). A Boolean subtraction is performed to remove the pins and the mandible from the "box-object." This mathematical operation produces hollow cylinders that transverse

the "box-object" and also leave behind a negative imprint of the contours of the angle of the mandible (Figure 10-3D). A file containing the computer data is used for fabrication of a stereolithographic template. The template is designed to fit the contours of the angle of the mandible, and once positioned it orients the drilling cylinders in their predetermined position in space.

At surgery, the angle of the mandible is exposed through a small Risdon incision (Figure 10-4A). Afterward, the stereolithographic template is placed on the angle of the mandible and the four pilot holes are drilled (Figure 10-4B). At this point, the authors recommend completing the superior portion of the osteotomy (Figure 10-4C). Once this part of the osteotomy is completed, the pins are inserted. The distractor is adjusted to the predetermined settings and installed on the pins (Figure 10-4D). The final step is to complete the osteotomy and to close the wound. After the latency period, the distractor is activated as indicated by the planning process.

Planning for Maxillary Distraction

Indications

Distraction osteogenesis has also been successfully used to treat patients with maxillary deformities.^{21,22} Until the advent of maxillary distraction, conventional orthognathic operations were the only techniques available for the treatment of patients with maxillary hypoplasia. In the majority of these patients, traditional orthognathic procedures produced excellent outcomes in an expeditious and cost-effective manner. Distraction osteogenesis of the maxilla appears to be superior to conventional orthognathic surgery in a select group of patients. This group includes cleft patients who need more than 6 mm of maxillary advancement, and noncleft patients who need advancements in excess of 10 mm.^{21,23} These patients need advancements beyond the physical limitations of conventional surgery. Distraction osteogenesis should not be used in patients who need segmentation of the maxilla, or in noncompliant patients.

There is no consensus on the appropriate patient age to employ distraction osteogenesis in the maxilla. It is customary to delay surgical treatment of maxillary deformities until the completion of skeletal growth. This is usually completed between the ages of 14 and 16 years in girls and ages 17 and 19 years in boys.²⁴ Surgery before the completion of maxillary growth can disrupt important growth sites, limiting future growth.²⁵ Even in conditions with limited maxillary growth potential, such as craniofacial synostosis and cleft lip and palate, early maxillary surgery may be not advisable. Continued mandibular growth in these patients may negatively affect their final

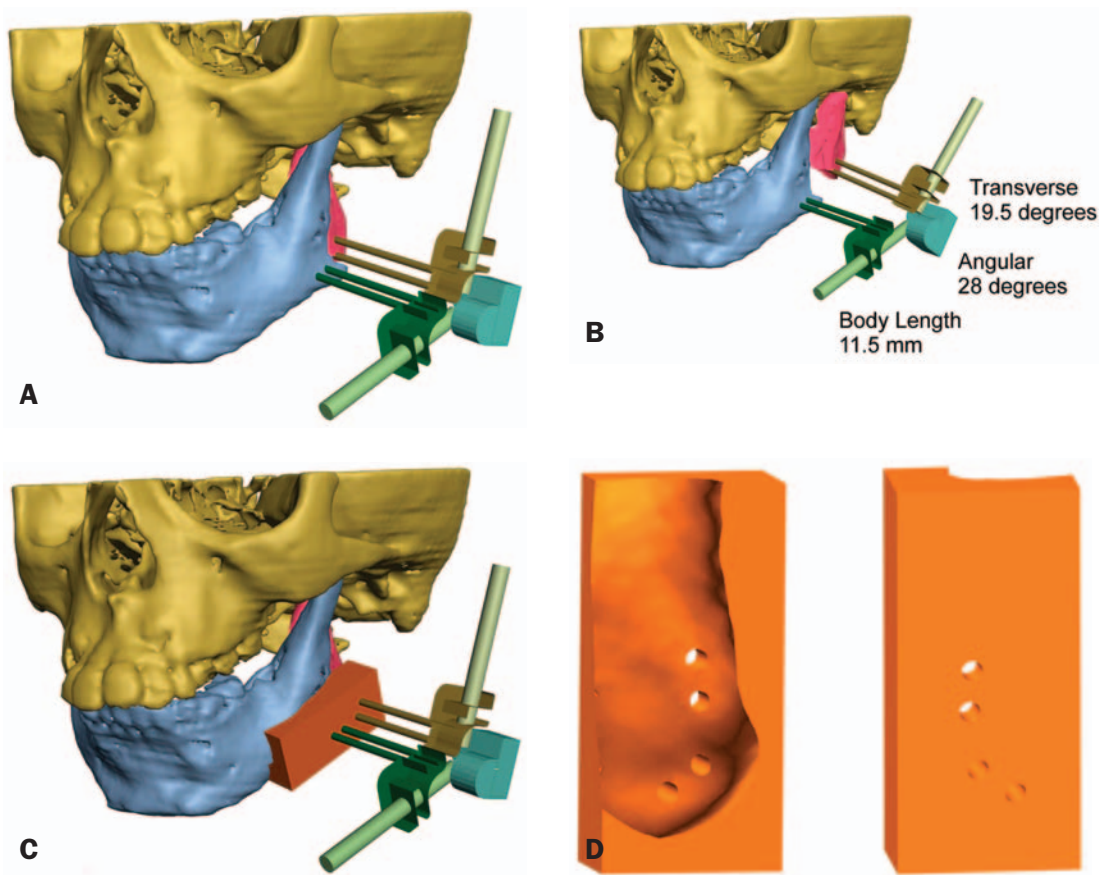


FIGURE 10-3 A, The virtual multiplanar device is installed on the mandible. B, Distraction recipe necessary for the distraction process. C, A computerized template is designed by a "box-object" encompassing the pins and the mandible. D, A Boolean subtraction is performed to remove the pins and the mandible from the "box-object." This mathematical operation produces hollow cylinders that transverse the "box-object" and also leaves behind a negative imprint of the contours of the angle of the mandible.

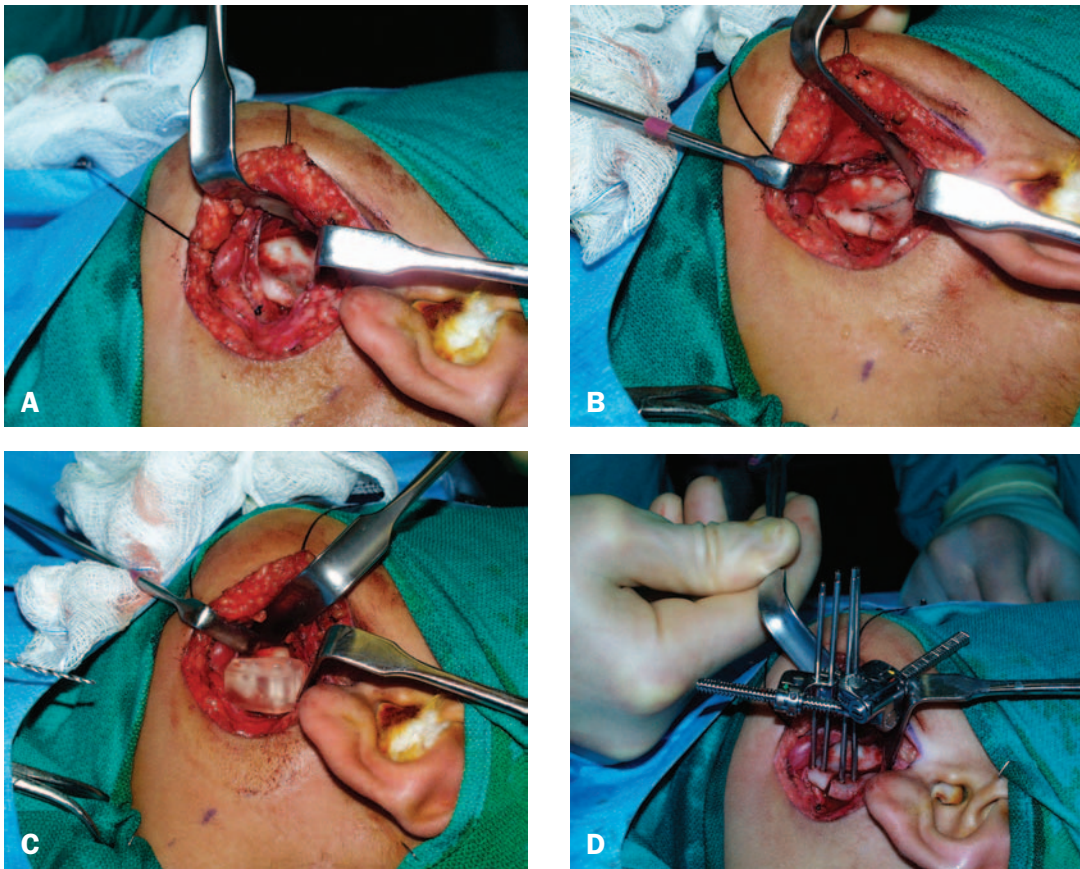


FIGURE 10-4 A, The angle of the mandible is exposed through a small Risdon incision. B, The stereolithographic template is placed on the angle of the mandible and the four pilot holes are drilled. C, The authors recommend completing the superior portion of the osteotomy. Once this is completed, the pins are inserted. D, The distractor is adjusted to the predetermined settings and installed on the pins.

outcome.²⁶ At present, this complication cannot be avoided, because there is no accurate way of predicting final facial growth.

Some authors have recommended the use of maxillary distraction in growing patients as young as 6 years of age.^{21,23,27} We have not endorsed this approach. Our experience with early surgery has made us aware of the deleterious effects that it can have on future facial growth and developing dentition. In spite of our concerns with early maxillary surgery, we have occasionally operated on young teenagers with severe maxillary hypoplasia and significant psychosocial problems. In these patients, it would be advisable to attempt age-dependent overcorrection. However, because good dental interdigitation is not possible in overcorrection, the potential for relapse may increase.²⁸ The patients and their parents understood the possible need for additional operations after the completion of growth.

Some authors have touted a lack of relapse as an advantage of distraction.^{21,29} However, we have experienced the relapse during the consolidation phase. Despite that the patients achieved the planned maxillary advancement at the end of the distraction phase, relapse still occurred. This indicated that the distractors may

overcome the resistances from the regenerate, scars, and surrounding soft tissues. A new force, capable of producing relapse, must have appeared during the consolidation phase. It is possible that wound contraction may have played an important role.²⁸

Planning

Maxillary distraction is not as complex as mandibular distraction. In patients with simple maxillary deformities, distraction planning can be accomplished using direct anthropometric measurements, dental models, and cephalometric radiographs. However, in patients with complex maxillary deformities, distraction planning is best accomplished using three-dimensional computer simulation.³⁰

The goal of maxillary distraction is to normalize the anteroposterior, vertical, and transverse positions of the maxilla. Additionally, at the completion of distraction, the occlusion should be ideal. As in the case of the mandible, the first step in the maxillary planning process is to build a computerized three-dimensional model of the facial skeleton. This model is constructed from a CT scan of the patient's maxillofacial region. After the model has been created, it is imported into a

computer program, which enables visualization and manipulation of the facial skeleton in three dimensions (Figure 10-5A).

The next step is to simulate the Le Fort I osteotomy and to move the segment to the desired final position. As with the mandible, the software can create an animation of the distraction process. This animation helps the surgeon visualize the path that the Le Fort segment should take during distraction. Using this technique, the authors have noted that this path is curvilinear in most patients. This curvilinear path is the result of the combination of translation and rotation of the maxilla during distraction. The computer simulation provides the surgeon with a recipe for distraction, which includes the length and direction of the advancement as well as the rotation necessary to place the maxilla in ideal occlusion (Figures 10-5B and 10-5C).

A common complication of maxillary advancement is the creation of an anterior open bite.^{28,31} This deformity is produced when the force of distraction is applied below the maxillary center of resistance. In simple terms, the center of resistance is the point at which a force, when applied, will produce linear displacement without rotation. Forces applied below the center of resistance will produce a counterclockwise rotation of the maxilla and an open bite (Figures 10-6A and 10-6B). This complication can be prevented by applying forces above the center of resistance, which will produce a clockwise rotation of the maxilla closing the open bite (Figures 10-6C and 10-6D). To plan maxillary distraction, it is important to calculate the maxillary center of resistance. Unfortunately, currently available software is unable to make this calculation. However, it is capable of calculating the "center of mass." Up to this point, the authors have assumed that the center of resistance corresponds to the center of mass. The authors recognize the inherent weakness of this assumption, but clinical results using this assumption have been good (Figures 10-7 and 10-8).

Planning for Distraction of the Midface

Indications

Distraction osteogenesis has been successfully used to treat patients with craniofacial synostosis syndromes.^{21,29,32} These syndromes include Crouzon's, Apert's, Saethre-Chotzen's, Pfeiffer's, and Carpenter's syndromes. These syndromes represent familial forms of synostosis, involving not only the cranial vault but also the cranial base and midface structures. The syndromes are characterized by shallow orbits with ocular proptosis, brachycephaly, and midface hypoplasia. Some patients may also exhibit orbital hypertelorism.³³

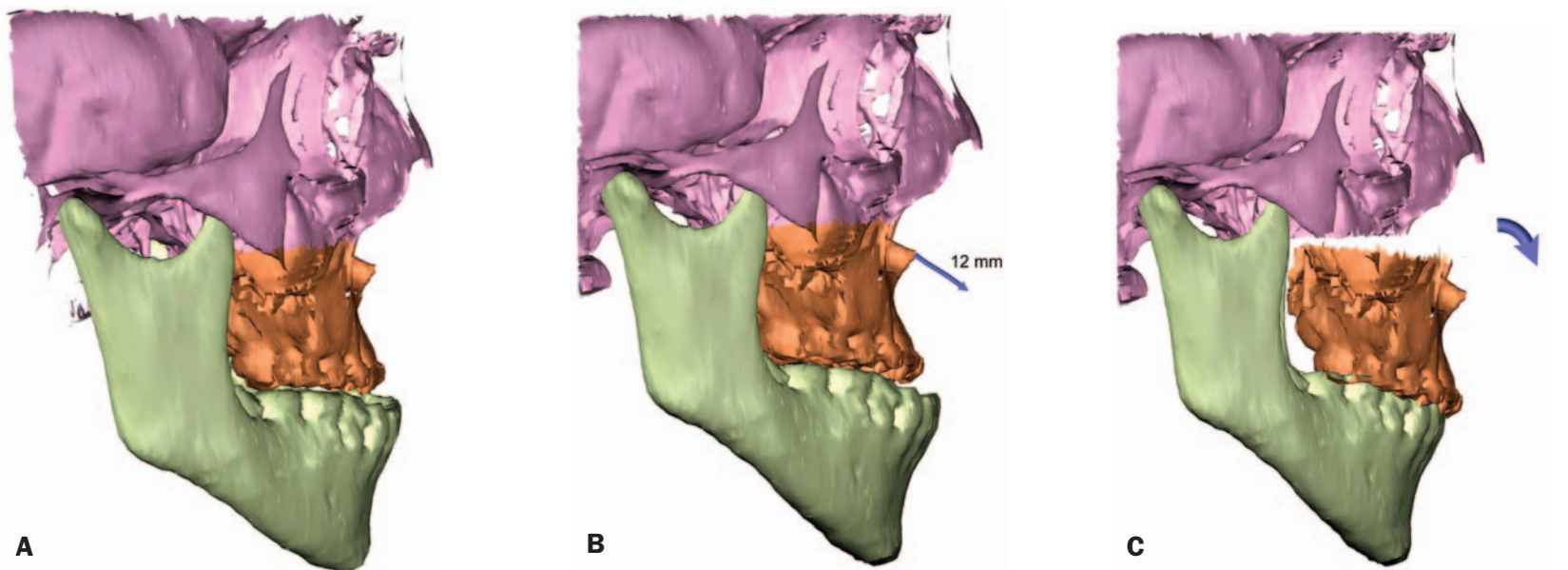


FIGURE 10-5 The three-dimensional reconstructed computed tomography scan of a 12-year-old girl with unilateral cleft lip and palate, and severe maxillary hypoplasia (A). The computer simulation provides a recipe for distraction. It includes the length and direction of the advancement (B) as well as the rotation necessary to place the maxilla in ideal occlusion (C). The distraction path is the result of the combination of translation and rotation of the maxilla.

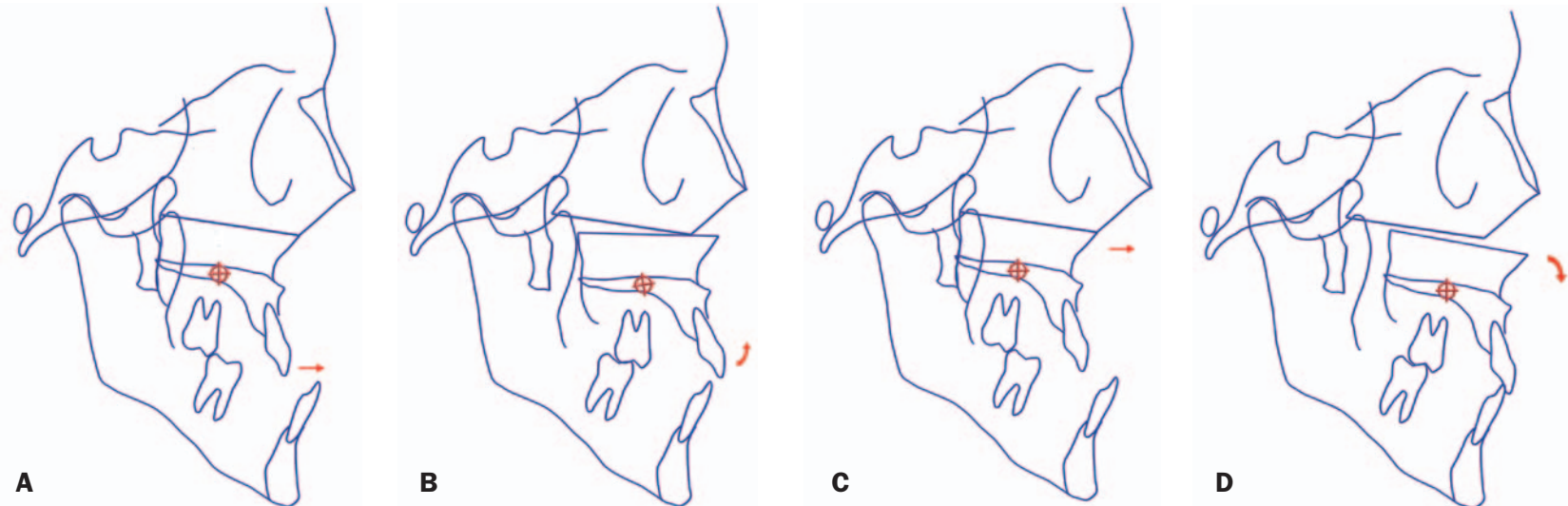


FIGURE 10-6 A common complication of maxillary advancement is the creation of an anterior open bite. This deformity is produced when the force of distraction is applied below the maxillary center of resistance (A). Forces applied below the center of resistance produce a counterclockwise rotation of the maxilla and an anterior open bite (B). This complication can be prevented by applying forces above the center of resistance (C), which will produce a clockwise rotation of the maxilla, thus closing the open bite (D).



FIGURE 10-7 Preoperative (A, B) and postoperative (C, D) photographs of the patient in Figure 10-5.

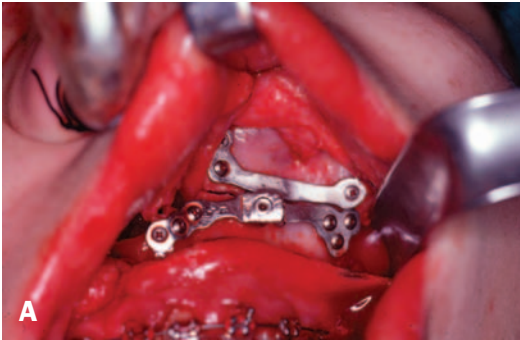


FIGURE 10-8 A, Intraoperative photograph demonstrating the use of a customized internal Le Fort I distractor. B, Lateral photograph demonstrating the distractor's activation rod.



The treatment protocol for these patients varies among craniofacial centers. The most common protocol involves a staged approach. The first operation in this approach is usually performed during infancy (3 to 12 months) and consists of suture release, decompression, and simultaneous cranial vault and upper orbital osteotomies, with reshaping and advancement. The second operation is usually performed between ages 5 and 7 years and involves the treatment of the orbitozygomatic deficiency. In between these two operations, it is often necessary to perform a repeat craniotomy–cranioplasty. The final operation is completed during adolescence and involves the orthognathic management of the residual maxillary deformity.³² In a few centers, a single operation (monobloc) is employed to treat the cranial vault, cranial base, and midface deformities.³⁴

Distraction has been used both in infancy and in childhood to advance a monobloc osteotomy and to advance a Le Fort III osteotomy.^{29,35–37} It has also been used for the late treatment of midface deformities in adults. The planning for distraction osteogenesis of the upper face and/or midface does not differ significantly from the planning for these operations without distraction. The first step always involves a systematic analysis of the deformity. The deformity should be quantified in three dimensions. The decision to complete a monobloc, facial bipartition, or a Le Fort III osteotomy to manage the horizontal, transverse, and vertical midface deficiencies will depend upon the patient's midface and anterior cranial-base morphology.^{30,33}

Planning

The planning for distraction of the midface is similar to the planning process used when these patients are treated without distraction.²⁹

The authors are currently using three-dimensional computer simulations to plan the treatment of these patients. The use of computer simulation allows for complete visualization of the deformity and the final outcomes. In addition, computer simulation has replaced the need for cephalometric radiographs, tracings, and dental models.

As with the mandible, the first step in our planning system is to build a computerized three-dimensional model of the facial skeleton. This model is constructed from a CT scan of the patient's maxillofacial region. After the model has been created, it is imported into a computer program, which enables visualization and manipulation of the facial skeleton in three dimensions. In addition, virtual models of the patient's globes are incorporated into the facial skeleton. Next, the osteotomies are simulated and the midface is positioned in the desired final position. The magnitude of the anterior advancement is determined by the sagittal relationships of the cornea to the nasion, lateral rim, and orbitale (Figure 10-9). The use of this relationship, as advocated by Mulliken and colleagues, helps prevent enophthalmos in patients with midface advancement.^{38–40} The authors have found the use of sagittal orbital–globe relationships in the prevention of enophthalmos superior to Chin and Toth's average porion to orbitale measurement, although comparison of the two methods often yields similar results.²⁹

A major advantage of three-dimensional computer models is the ability to visualize and adjust horizontal and vertical relationships in the orbit. The main goal of midfacial advancement in these patients is to normalize the anatomy of the orbitozygomatic region. A recent retrospective study by Fearon also suggests that in growing children, the ideal vector for distraction is determined by the malar position and not by

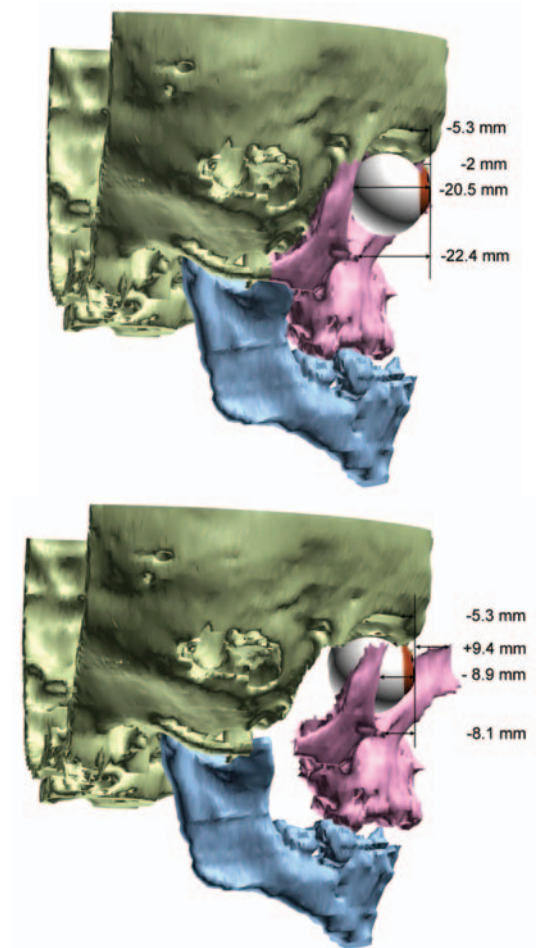


FIGURE 10-9 Three-dimensional reconstructed computed tomography (CT) scan of a 6-year-old patient with Crouzon's syndrome. Virtual models of the patient's globes have been incorporated into the three-dimensional CT of the maxillofacial skeleton. The magnitude of the anterior advancement is determined by the sagittal relationships of the cornea to the nasion, lateral rim, and orbitale.

dental occlusion.⁴¹ A Le Fort III osteotomy is indicated in the treatment of midface hypoplasia, if the contour of the forehead and anterior projection of the supraorbital ridge are normal and if there is no hypertelorism. A monobloc osteotomy is indicated in midface hypoplasia, if there is decreased anterior projection of the supraorbital ridge and an abnormal contour to the forehead (Figure 10-10). If orbital hypertelorism is present, then a facial bipartition can be completed and the orbits can be repositioned medially.³³ The normalization of the vertical and horizontal dimensions of the orbital rim takes precedence over the normalization of the occlusion. Attempts to simultaneously normalize the occlusion can produce enophthalmos and distortion of the orbitozygomatic region (Figures 10-11A and 10-11B). Normalization of the occlusion is best accomplished by a Le Fort I osteotomy at the completion of facial growth (Figures 10-11C and 10-11D). Figures 10-12 and 10-13 present the results of a patient who underwent Le Fort III distraction following this planning protocol.

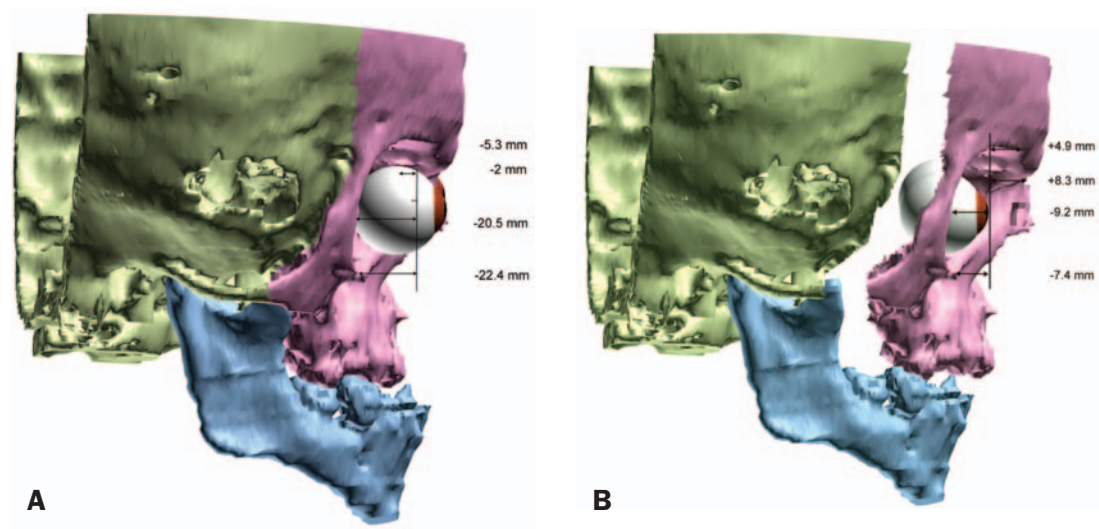


FIGURE 10-10 A, Preoperative sagittal orbital–globe relationships of the same patient in Figure 10-9. B, Simulation of monobloc advancement to normalize the sagittal orbital–globe relationships.

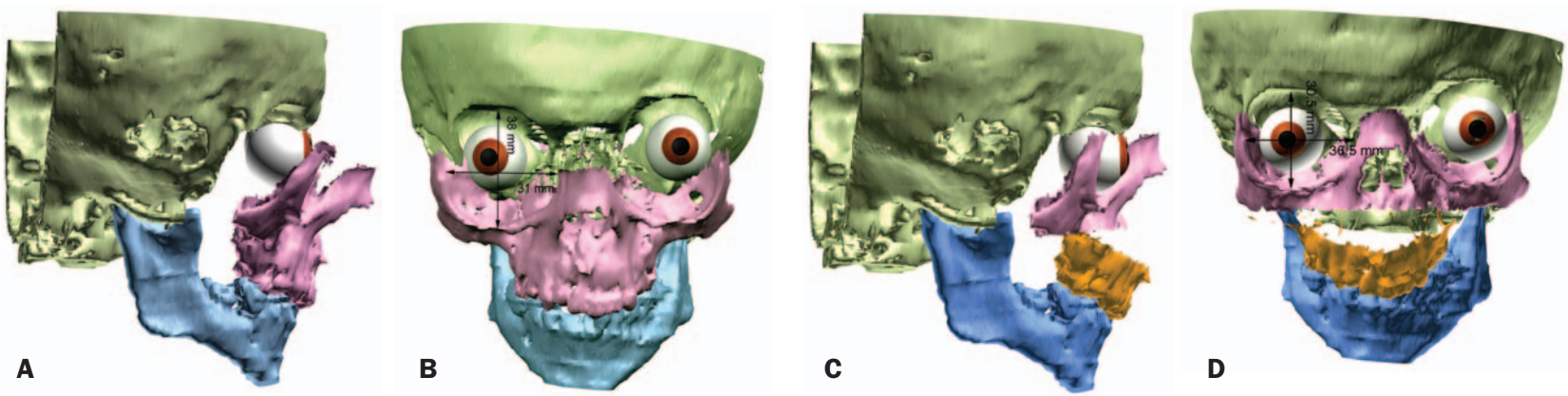


FIGURE 10-11 Attempts to simultaneously normalize the occlusion in the same patient in Figure 10-9 can produce enophthalmos and distortion of the orbitozygomatic region (A, B). Normalization of the occlusion is best accomplished by a Le Fort I osteotomy at the completion of facial growth (C, D).



FIGURE 10-12 Preoperative (A, B) and postoperative (C, D) photographs of the same patient in Figure 10-9, who underwent Le Fort III distraction.

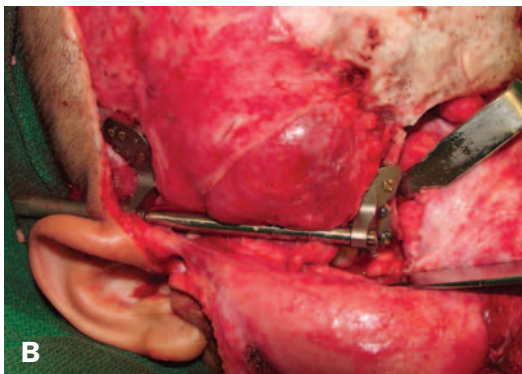
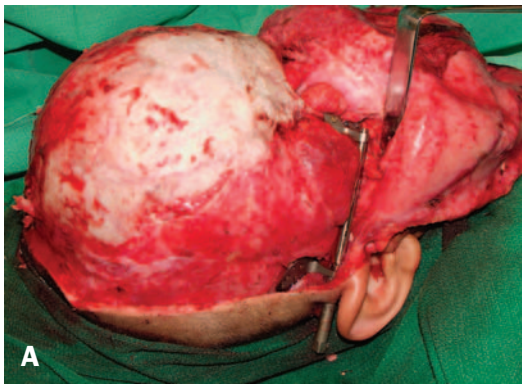


FIGURE 10-13 A, B, Intraoperative photographs demonstrating a customized internal Le Fort III distractor. C, Lateral photograph of the patient with the distractor device in place.

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Craniofacial Growth Consideration of Early Surgical Intervention

Peter H. Buschang

The decision of whether or not to perform maxillofacial surgery in growing children depends ultimately on the relative benefits and risks. In order to establish risks and benefits, the concept of critical periods must be considered, because potentials differ (both among and within individuals) and change over time. Critical periods occur when changes are taking place most rapidly. As with any other system, either organic or inorganic, human growth is most vulnerable to negative insults when morphologic and physiologic changes are occurring most rapidly. Importantly, systems are also most vulnerable to positive insults during critical periods (Figure 11-1). The growth response of any system to insults during

critical periods depends on the nature of growth and the relative growth of the component parts. The response can be detrimental or beneficial; the potential for beneficial growth modification provides tremendous clinical opportunities. Systems are not vulnerable to insults that occur before or after a critical period.

Knowledge of critical periods is fundamental for establishing the propriety of maxillofacial surgery for growing children and adolescents. Surgery has traditionally been rationalized based on its face validity. However, with the medical community gravitating toward an objective and evidence-based health care system, the professional and legal organizations have moved

toward content and predictive validity. Content validity is based on lists of criteria that define surgical treatment. Predictive validity establishes the link between the treatment criteria and quality of life. Professionally, these criteria establish an objective basis for diagnosis and treatment planning. Legally, they provide a standard of care against which judgments can be made. In terms of surgical treatment, the prognosis is perhaps the most important factor determining its validity.

Nature of Craniofacial Growth

Prognosis during periods of growth is complicated by the myriad of changes that occur or have the potential of occurring. A morphologic component's susceptibility to insults depends largely on the mechanisms controlling its growth. As described by van Limburgh, postnatal growth of the craniofacial complex is controlled by interacting genomic and environmental determinants.¹ The genomic determinants include intrinsic genetic factors and epigenetic factors, with endocrines, cytokines, and growth factors providing the control mechanisms. Epigenetic and the environmental factors can be broken down into local and general types. Craniofacial growth actually displays variable amounts of intrinsic genetic control, ranging from little or no control of occlusal relationships to relatively higher control for skeletal units.²⁻⁶

Chondral growth, originating in cartilage and achieved by interstitial growth, occurs at the cranial base synchondroses and nasal septum. Growth of cartilage is interstitial in nature; chondrocyte multiplication and extracellular matrix synthesis are primarily controlled by intrinsic genetic and epigenetic factors. During growth of primary cartilage, the matrix effectively isolates the dividing chondrocytes from environmental influences. Chondral growth of temporomandibular joint cartilage is distinctly different. Because secondary cartilage grows primarily by apposition, with proliferation occurring in progenitor cells that are surrounded by substantially less matrix, mechanical stimulation alters both the

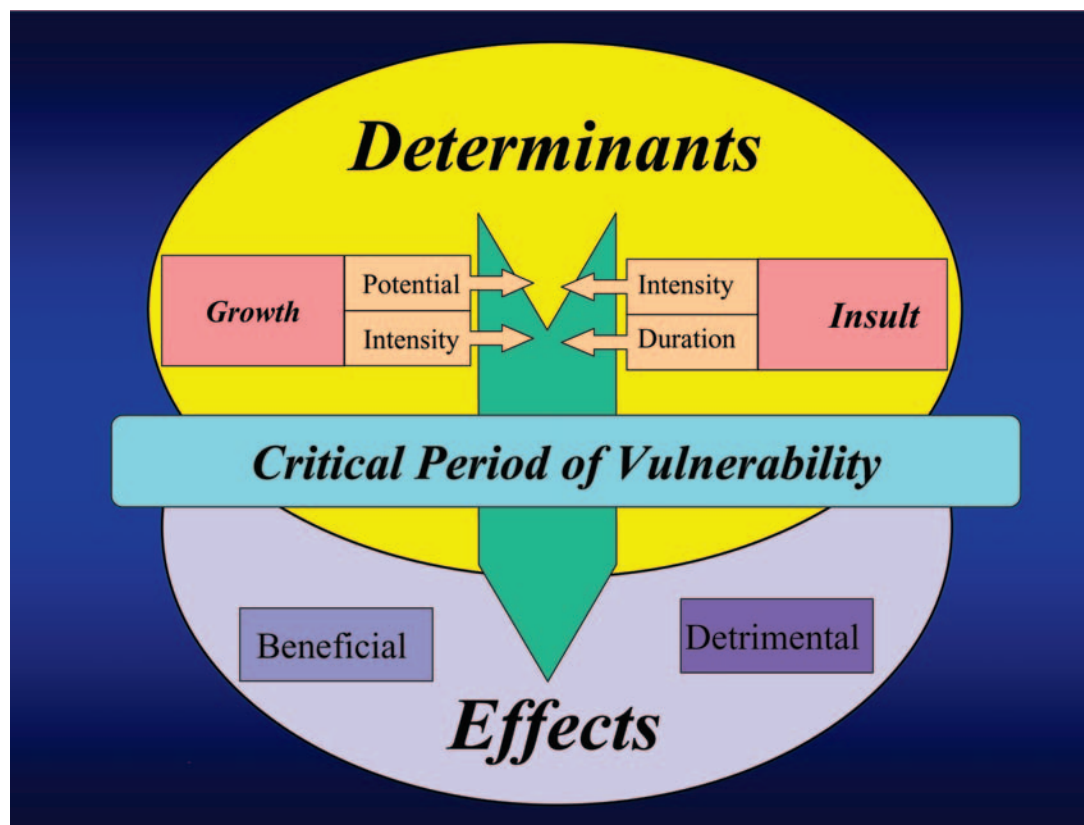


FIGURE 11-1 Determinants and effects of vulnerabilities during critical periods.

growth and differentiation of condylar secondary cartilage cells.⁷

Sutural growth is appositional in nature and under both epigenetic and environmental control. It is associated with osteoblasts, which are responsible for the apposition that occurs on both sides of the suture. Assuming that synostosis has not occurred, any force that separates a suture will produce sutural growth. Conversely, anything that prevents normal separation of sutures will inhibit sutural growth (Figure 11-2).

Sutural growth is closely related with periosteal growth. Periosteal growth is also influenced by epigenetic and environmental factors. Whereas sutural growth occurs at the bone edge, periosteal growth occurs on the bone surface. In terms of clinical application, it is well known that mechanical forces and alterations of normal biomechanical forces can have a profound influence on periosteal growth.⁸⁻¹¹ As established by Wolff, the trabecular architecture of bone reflects biomechanical forces¹²; modification of the stress pattern produces changes of the internal architecture of bone. Theoretically, it can be

argued that *any* change in a patient's biomechanical environment due to surgical repositioning might be expected to produce a periosteal and endosteal growth response as the system reestablishes its equilibrium.

Relative Craniofacial Growth

There is great variation in relative postnatal growth potential of the various components of the craniofacial complex. It was originally believed that craniofacial growth could be categorized as either neural or somatic, following Scammon's neural and somatic growth curves, respectively. In 1983, Buschang and colleagues introduced the concept of craniofacial growth maturity gradient (CGMG), which implies a continuous range of variation in relative growth potentials between craniofacial components (Figure 11-3).¹³ The CGMG is not unique to humans; it has recently been shown to apply across diverse species.^{14,15} The components' relative growth potentials are in part due to the type of tissue involved and their environment circumstances.

Importantly, it must be realized that most craniofacial components have already attained at least 70% of their growth potential by 4.5 years of age.¹³ The average 4.5-year-old child has already attained 91 to 93% of his/her adult cranial vault height (see Figure 11-3); the cranial base is 79 to 87% complete, and the maxilla is 73 to 80% complete. The mandible, which is the least mature component, is 66 to 76% complete at the same age. The anteroposterior (AP) growth potentials of the cranial base, maxilla, and mandible are less (ie, have completed more of their growth) than their vertical counterparts. Additionally, males have greater growth potential than females.

By the time children are 13.5 years of age, relative growth potential is markedly reduced, to 5% or less for most components.¹³ The only exception is vertical mandibular growth, which retains considerable growth potential, especially for boys. Interestingly, the growth potential for ramus height for both males and females is greater than statural growth potential during the post-pubertal years. This limits the ability of hand-wrist radiographs to define the end of active mandibular growth.

Based on relative growth potential, a component's susceptibility to potential surgical insult depends primarily on its location, on the patient's age, and, less so, on gender or orientation (vertical versus horizontal) (Figure 11-4). The response of the various craniofacial structures to treatment effects has been experimentally shown to be directly related to the structure's relative maturity.¹⁶

Consensus Statements and Surveys

There is only one consensus statement that provides guidelines for performing surgery during active growth.¹⁷ It pertains to seven teams of maxillofacial surgeons and orthodontists representing five European countries, who came to the consensus that for most deformities (note: patients with severe syndromic facial deformities were not considered), facial osteotomies should be delayed until growth is complete. Exceptions during the first 10 years included surgical intervention for cases with serious restriction of mouth opening, grafting of hemifacial microsomia, resection plus reconstruction in cases of condylar hyperplasia, and surgery patients with facial clefts. Although there was a preference to wait until the end of growth, it was noted that osteotomies for the correction of Class II deep bite could be performed during the first half of the second decade (ages 10 to 15 years) of life.

A more recent survey of 334 Canadian orthodontists clearly showed that patient age influences the timing of orthognathic surgery.¹⁸ The average responding orthodontist indicated that surgery should not be performed until 14.9 years for

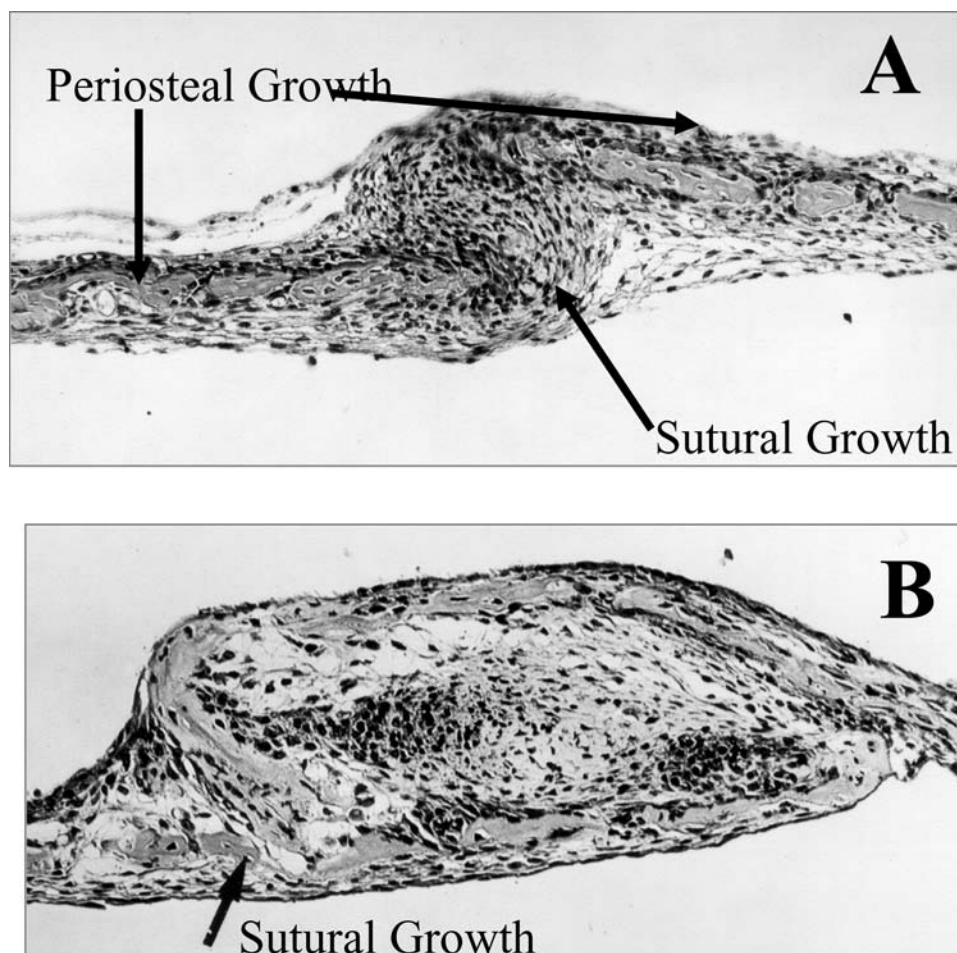


FIGURE 11-2 A, Normal periosteal and sutural growth in a young rat. B, Abnormal sutural growth, due to absence of signals from dura mater.

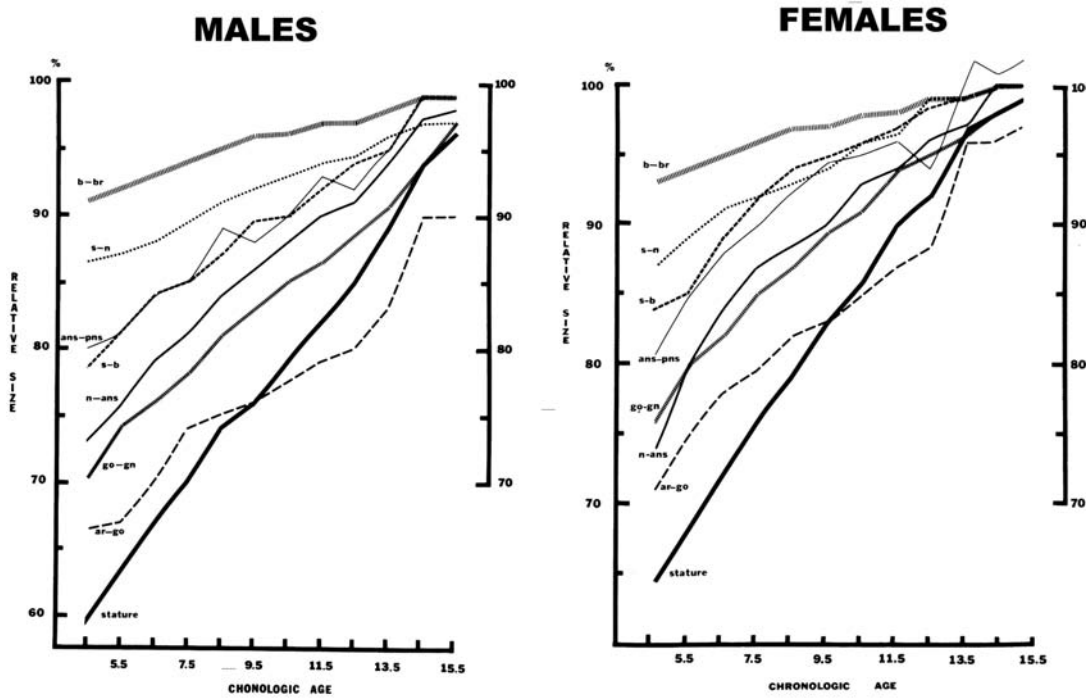


FIGURE 11-3 Percent adult status of seven craniofacial dimensions and stature for males and females. Reproduced with permission from Buschang PH et al.¹³

females and 16.3 years for males. A minority, 32%, recommended surgery as an option before 8 years of age. Interestingly, the younger and presumably less experienced orthodontists were more willing to perform surgery during growth than the older orthodontists.

Benefits of Maxillofacial Surgery During Growth

There are three general potential benefits of performing surgery in growing individuals. Most importantly, early correction of deformities could have profound influence on patients' self-perception, socialization, and interpersonal relationships. Facial appearance has been shown to be fundamental in determining interpersonal relationships.^{19,20} Childhood and adolescence are critical periods of psychological development, because the way in which individuals see themselves and how others see them can have profound consequences on life decisions.^{21,22} Because differences in behavior toward attractive and unattractive subjects have been documented, waiting to perform surgery in adolescents with severe skeletal deformities may also have detrimental effects on their self-image.^{23,24} Therefore, the risk of psychological consequences of delaying surgery may outweigh the benefits of waiting.

In addition, there may be better long-term stability of the muscles, bones, and joints if intervention occurs at a time when the deformity has not become fully expressed and when the individual is perhaps best able to adapt. In other words, early intervention permits more conservative surgical procedures to be performed because the dysplasia has not fully developed. This translates into less potential insult to the system, reduced risk of relapse, and better long-term stability. Children and adolescents might also be expected to better adapt and heal post-surgery than adults. Although more studies are needed, it is also reasonable to assume that appropriate forms of early intervention could also correct functional deficits that produce abnormal growth patterns. In fact, there is evidence that functional deficits are difficult to correct in older children.^{25,26}

Finally, early surgery could reduce treatment time for patients with severe deformities by obviating first "attempts" to correct deformities with orthopedic appliances.²⁷ Despite the fact that nonsurgical orthopedic corrections have been well established in animal studies, treatment outcomes for patients have demonstrated very limited abilities to modify midfacial or mandibular growth.²⁸⁻³³ Assuming that the response potential to orthopedic correction is related to the individual's growth potential, Figure 11-5 shows that orthopedic outcomes for individuals with less than average growth potential is extremely limited and may be insufficient to correct clinically significant discrepancies.^{34,35}

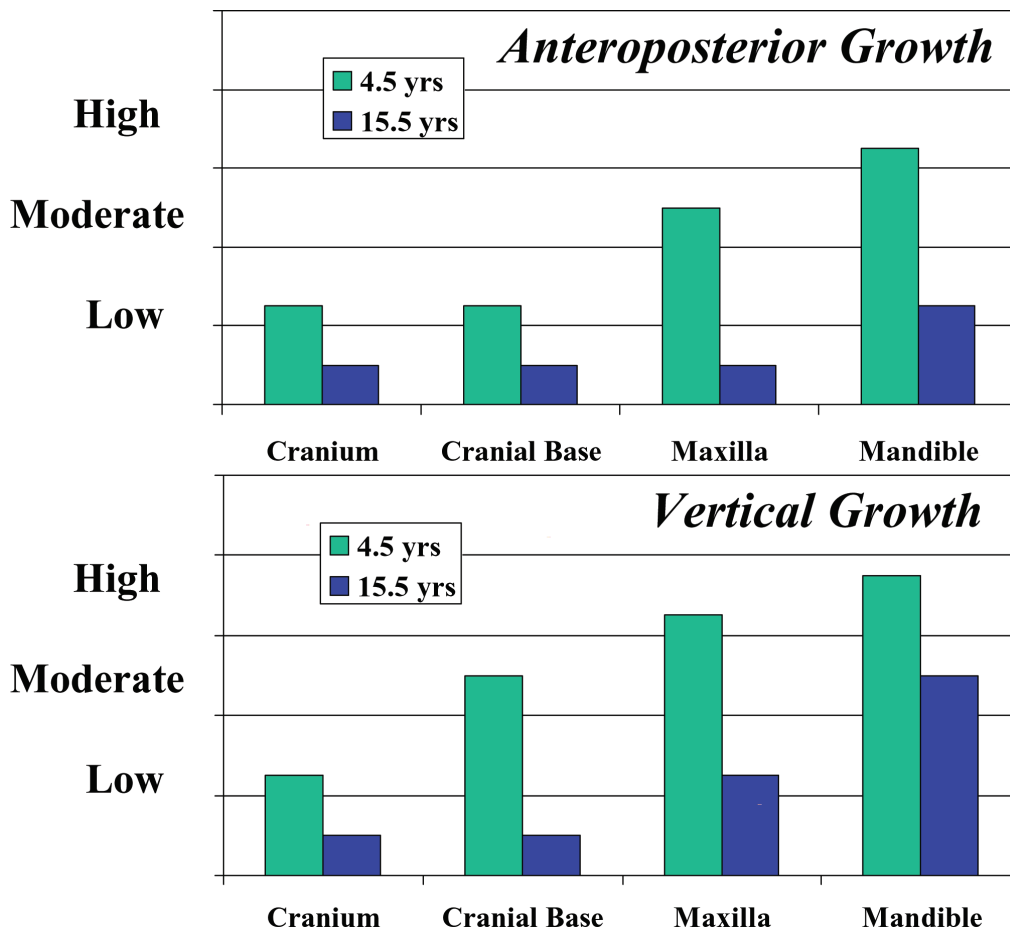


FIGURE 11-4 Relative susceptibility of craniofacial components based on maturity, location, and orientation.

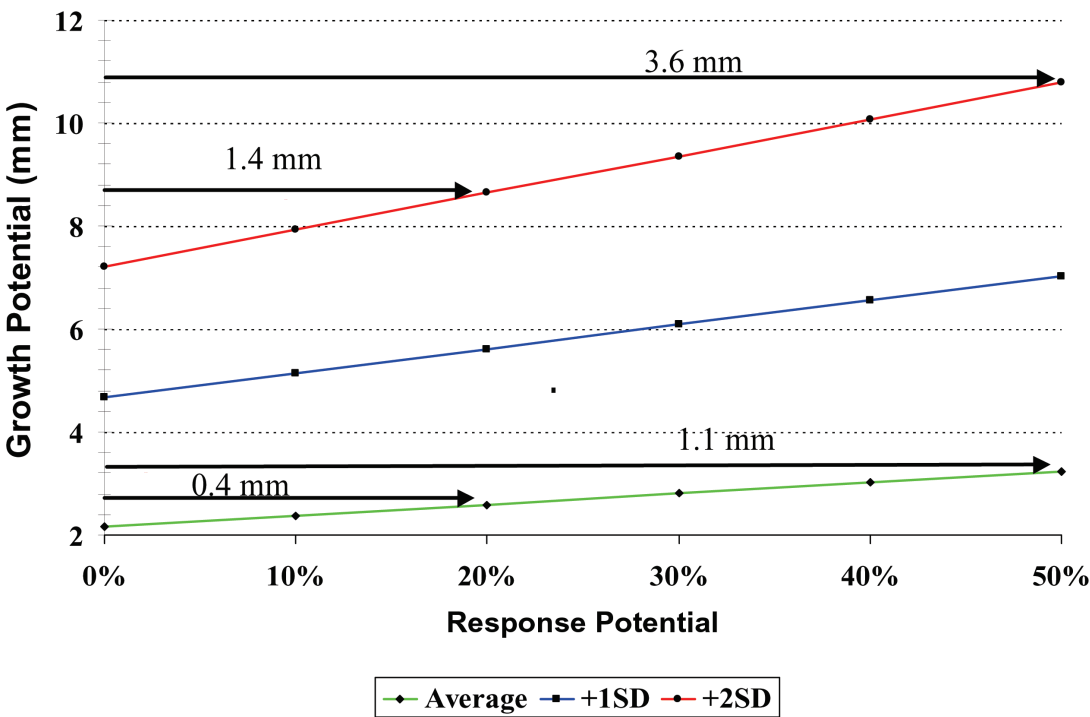


FIGURE 11-5 Simulation of the response potential of anterior growth displacement of the chin for three hypothetical girls with average and above average (+ 1 SD; + 2SD) growth potential.

Risks of Maxillofacial Surgery During Growth

The primary risk of performing surgery during growth is in *not knowing* how surgery will affect growth and how growth might affect the surgical outcome. Maxillofacial surgery in growing patients is delayed because the effects of surgery on subsequent craniofacial growth are not well understood.¹⁸ There are three possible detrimental outcomes of early surgery³⁶:

1. If self-correction occurs, then surgery might be performed unnecessarily.
2. Surgery could worsen an already abnormal growth pattern.
3. If surgery does not correct the growth pattern, then an abnormal growth pattern subsequent to surgery could reestablish the deformity.

Prelude to the Review of Existing Studies

The following review pertains exclusively to surgical outcomes and is intended to be representative rather than exhaustive. The descriptions provide the content validity for different types of maxillofacial surgery. The growth effects of maxillary and mandibular surgeries will be evaluated separately. Both the animal and clinical literature will be included. It must be emphasized that the animal literature is limited in its ability to elucidate postsurgical growth, because the animals typically display *normal* growth prior to surgery. However, in terms of internal validity, animal

studies provide stronger evidence of treatment effects because of their ability to control bias.

The existing clinical literature pertaining to the relative risks and benefits of early surgery is both fragmented and limited. Most of the earlier reports are anecdotal, making synthesis difficult and comparisons impossible. The majority of studies are based on small sample sizes, which decreases their power and reliability. Studies are often biased because they describe mixtures of various deformities and treatments. Interpretation of studies that do not separate postsurgical growth and postsurgical relapse is also problematic. Controls are often missing or not properly matched. Finally, there is great variability and little control over presurgical and postsurgical orthodontics.

The effects of distraction osteogenesis on craniofacial growth, and vice versa, have not been well investigated. For these, as well as other novel surgical procedures, we must rely on existing surgical literature. This review will first describe the relationships between growth and maxillary surgery, for which a reasonable body of literature exists, followed by the relationship between growth and mandibular surgery, which remains less well understood.

Maxillary Surgery

Le Fort I Osteotomies

Clinical Studies

The clinical studies clearly demonstrate postsurgical growth potential in the vertical

dimension. However, excessive vertical growth potential does not appear to be normalized with surgery. Postsurgical horizontal maxillary growth is affected by surgery; early surgery limits normal anterior displacement and compensatory posterior growth modeling.

Epker, Washburn, and colleagues have suggested that growth following surgical correction of vertical maxillary excess in adolescents (ie, that it follows more normal patterns).^{37,38} They evaluated 12 patients, 10 to 16 years of age, who had undergone 5.3 mm superior repositioning of the maxilla and were followed up 36.7 months postsurgery. Their postsurgical results showed vertical growth and no significant AP changes. They indicated that surgical damage to the nasal septal cartilage might have been responsible for the decreased AP growth. Although no direct comparison with untreated controls was made, they reported that maxillary growth “approaches normal.” Without adequate controls, they suggested that “the disproportionate growth that is characteristic of vertical maxillary excess may be favorably affected by such early surgical intervention.”

Vig and Turvey evaluated the vertical growth of 17 girls and 3 boys (14.9 years of age at the time of surgery), followed up 3.3 years postsurgery.³⁹ All were treated with Le Fort I downfracture osteotomies and maxillary superior repositioning (6 patients had mandibular sagittal split osteotomies). None of the patients had rigid fixation. All cases were impacted at least 2 mm. Vertical growth continued postsurgically, most of which was ascribed to maxillary dentoalveolar development. However, the open-bite tendency was not reestablished.

Mogavero and colleagues evaluated the effects of superior repositioning by Le Fort I osteotomy on maxillary growth in 48 patients; 23 were stabilized with rigid fixation and 25 with wire fixation.⁴⁰ Prior to surgery, there were no significant differences in vertical or AP maxillary growth compared with untreated controls, who were matched based on age, sex, and mandibular plane angles. After surgery, there was significant vertical maxillary growth with no significant differences between the two surgical and control groups (Figures 11-6 and 11-7). Horizontally, the rigid fixation group showed relative maxillary stability, as did the untreated controls. The wire fixation group showed posterior movement of the maxilla, indicating relapse.

More recently, Mojdehi and colleagues evaluated 15 actively growing patients who had undergone superior maxillary repositioning by Le Fort I osteotomies.⁴¹ They demonstrated a decrease in horizontal maxillary growth compared with closely matched controls. They also showed that early maxillary impaction did not normalize or inhibit their vertical maxillary excess growth patterns.

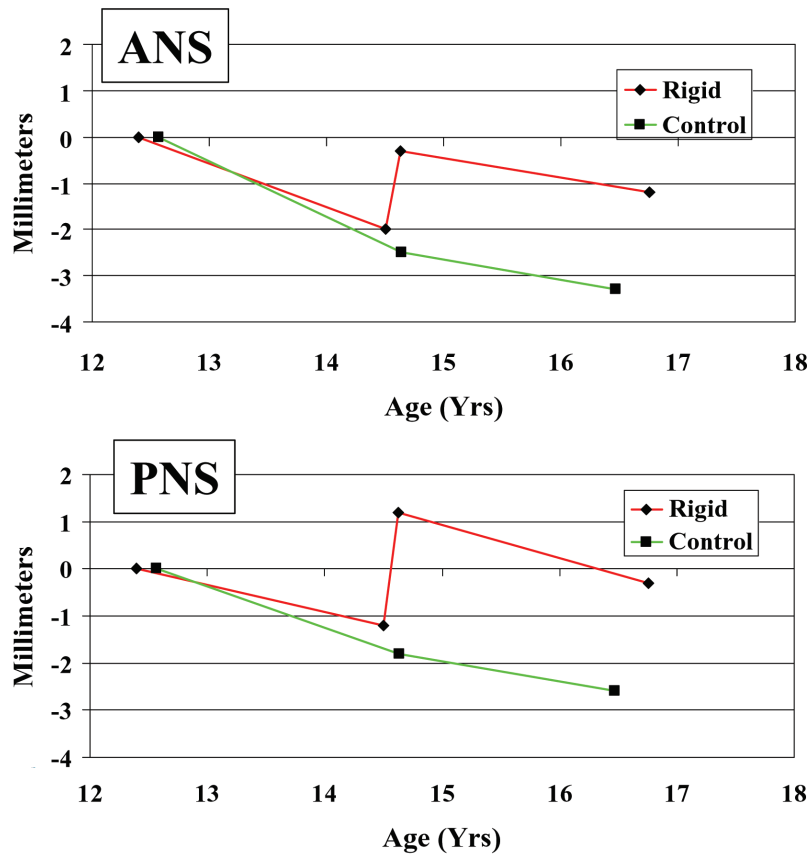


FIGURE 11-6 Presurgical, surgical, and postsurgical vertical changes at the anterior (ANS) and posterior (PNS) nasal spine for the rigid fixation group and controls.

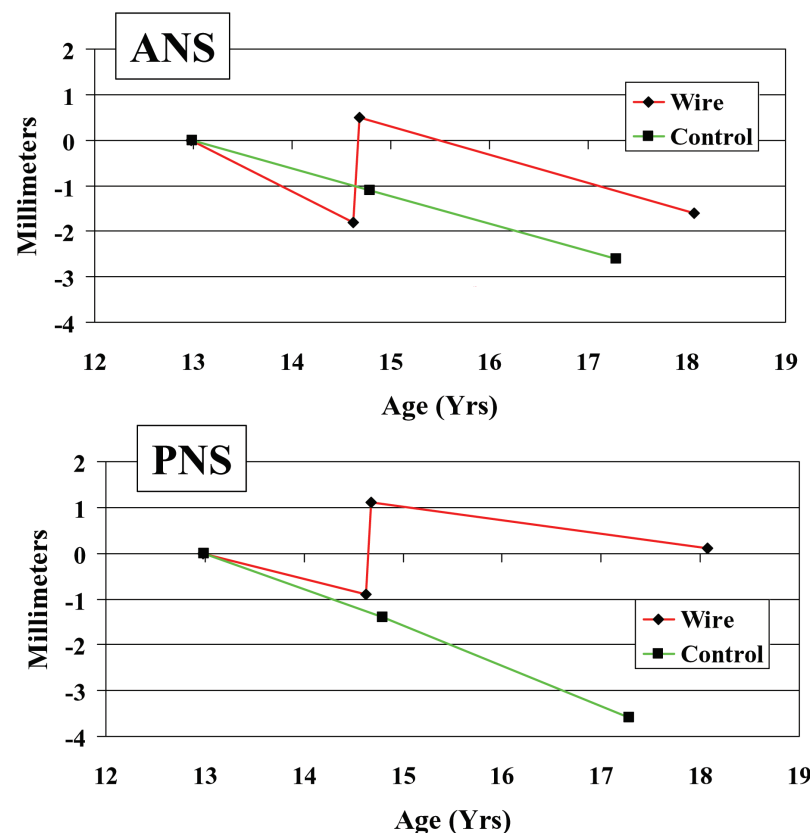


FIGURE 11-7 Presurgical, surgical, and postsurgical vertical changes at the anterior (ANS) and posterior (PNS) nasal spine for the wire fixation group and controls.

Experimental Studies

Animal studies show substantial postsurgical reductions in growth rates. Anteroposterior maxillary growth rates, which were reduced 33 to 66%, showed the greatest potential for surgical insults. The animal literature substantiates the clinical findings of reduced AP growth and continued vertical growth.

In 1983, Nanda and colleagues reported the effects of Le Fort I osteotomies on seven adolescent *Macaca fascicularis* monkeys.⁴² Compared with the controls, the operated-upon animals displayed decreased vertical posterior maxillary growth rates and reduced horizontal premaxillary growth rates. A follow-up study showed that monkeys with Le Fort advancements of 4 mm grew less than unoperated control animals; monkeys that had at least 5 mm advancement and 2.5 mm impaction showed the greatest growth deficits.⁴³ Vertical and the horizontal growth were both significantly less in the experimental than in the control animals. The surgery retarded, but did not arrest, AP growth. Interestingly, the mandibular growth pattern followed the maxilla's pattern in all the experimental groups, resulting in maintenance of the postoperative Class II malocclusions. The authors attributed the growth differences between the two experimental groups to more extensive injuries in the septovomer region of animals that had advancements and impaction. The septum was resected approximately equal to the amount of impaction. On that basis, the authors suggested that total alveolar osteotomies may be the surgery of choice to minimize the risks of reduced horizontal growth in younger individuals.

Shapiro and colleagues, and Kokich and Shapiro compared 3 control and 3 experimental monkeys that had Le Fort I maxillary osteotomies with wire fixation.^{44,45} The maxilla was advanced 8 mm. There was less than 25% relapse of the skeletal units superiorly and posteriorly. No further relapse was seen 6 weeks postsurgery. The results again showed that maxillary osteotomies adversely affected maxillary growth in the AP plane. The maxilla grew mostly inferiorly, changing the overjet to edge-to-edge bite. Over the long term, anterior cross-bites were produced in all three experimental animals, because relative to the mandible, the maxilla grew more inferiorly than anteriorly. They concluded that maxillary advancement osteotomies in young growing monkeys adversely affects maxillary growth in the AP plane of space. They suggested that disturbance may be due to (1) elimination of potential growth influence of the nasal septum after separation of the vomer and maxilla during surgery, (2) inhibiting influences of stretched soft palatal tissues, or (3) potential growth-inhibiting influence of scar tissues.

Le Fort III Advancements

Clinical Studies

The effects of Le Fort III osteotomies on facial growth remain controversial. The earlier, largely anecdotal, studies are contentious, with some suggesting that normal maxillary growth takes place postoperatively and others concluding that there was little or no sagittal maxillary growth following surgery.^{46–50}

Evaluation of postsurgical growth is complicated, because unoperated children with craniofacial synostosis or CAP (Crouzon's, Apert's, Pfeiffer's) syndromes present with reduced midfacial growth. Kreiborg and Aduss, and Coccato and colleagues have reported minimal growth of the entire midfacial complex for untreated individuals with CAP syndromes^{51,52}; Bachmayer and colleagues showed that children with untreated CAP syndromes have growth deficits mainly in the vertical dimension.⁵³

McCarthy and colleagues evaluated 12 patients with CAP syndromes who had undergone Le Fort III advancement at 5.1 years and were followed for 5 years.⁵⁴ Five of the patients, who had been advanced 9.4 mm, maintained the position of the midface; 5 patients, whose midface had been advanced 10 mm, showed mainly inferior movement of the midface postoperatively; and only 2 of the patients, advanced 10.8 mm, demonstrated significant anterior movement of the midface. They concluded that there is vertical growth of the midface postsurgically but little or no AP movements following Le Fort III osteotomies in young children.

Bachmayer and colleagues followed 19 children with CAP syndromes who had undergone Le Fort III advancement osteotomies for an average of 5.3 years.⁵³ Horizontal maxillary growth (0.1 mm/year) was significantly less than that of children with unoperated CAP syndrome (0.7 mm/year) and normal control children (1.3 mm/year). Vertical maxillary growth was similar to that seen in the unoperated CAP syndromes and control children. They concluded that Le Fort III osteotomies are justifiable for physiologic and psychological reasons, but that owing to the lack of subsequent horizontal growth, maxillary advancements will probably be required at the completion of growth. A limitation of this study was their use of cross-sectional control data for the unoperated CAP syndromes children and normal children.

Experimental Studies

Munro reported that Le Fort III osteotomies had little or no effect on overall skull growth.⁵⁵ He evaluated 25 pigs (5 weeks of age), including four experimental groups subjected to facial operations of different severity (elevation of periosteum, osteotomy only, osteotomy immobilized by wire fixation, with or without bone grafts) and a control group. The animals' body weights

increased tenfold and their skull size doubled. Munro reported no statistical intergroup differences. However, because samples were too small to ensure adequate power (ie, rule out possible Type II errors), it may be premature to conclude that Le Fort III osteotomies have no effect on skull growth. The Figure 2 in Munro's paper indicates that postoperative (8 months) skull length had increased 7 to 11% less in the experimental than in the control groups. Interestingly, the pigs that were only subjected to periosteal elevation had similar amounts of growth as those that had osteotomies only.

Cleft Lip and Palate

Although the effects on vertical and transverse growth have not been adequately investigated, it has been well established that surgical repair of the unilateral complete cleft lip, alveolus, and palate produces midfacial retrusion.^{27,56–61} Rehrmann and colleagues suggested that primary osteoplasties of alveolar clefts also produce growth deficits in the vertical and transverse dimensions.⁶² Long and colleagues, evaluating growth in maxillary width following pharyngeal flap surgery in 17 patients between 5 and 7 years of age, showed no alteration in the transverse growth of the jaws or dental arches compared with a matched sample of untreated patients.⁶³

It has also been reported that vertical growth of the posterior maxilla in unilateral cleft lip and palate patients is affected by early intervention. Buschang and colleagues evaluated 32 children, 5 to 8 years of age, treated during the first 13 months of life for unilateral cleft lip and palate.⁶⁴ Compared with age- and sex-matched untreated control children whose ANB angles were within ± 1 SD of the cleft sample's mean, the operated-upon children differed primarily in the posterior aspect of the maxilla, which was vertically shorter and horizontally longer in children with the unilateral cleft lip and palate (Figure 11-8). Ross and

Johnston suggested that the more superior position of the posterior maxilla might be due to surgical scar tissues joining the maxilla, palatine bone, and pterygoid plates.⁶⁵ The scar tissue could be acting as a type of maxillary "ankylosis." It has also been argued that the pharyngeal flap surgery might have a tethering effect, maintaining the position of the posterior maxilla.⁶³

There is also good evidence that all presenting problems do not respond equally to surgery. Kapucu and colleagues compared 10 adults with unilateral cleft lip and palate, who had only lip repair during childhood, with 30 adults who had lip and palate repair.⁶⁶ Although both groups showed significant maxillary retrusion compared with normal controls, there were no significant differences between the two treated unilateral cleft lip and palate groups. Because of the small sample size, it is likely that the power of the test was insufficient to detect differences.

In one of the most comprehensive studies to date, Normando and colleagues showed significant differences in maxillary growth between large samples of patients with unilateral cleft lip and alveolus, isolated cleft palate, and complete unilateral cleft lip and palates.⁶⁷ Compared with unoperated patients, cheiloplasty resulted in significant modeling in the anterior alveolar region, causing a repositioning of ANS and A points. The greatest growth effects were observed for the cleft lip, alveolus, and palate group, for whom reconstructive surgery produced significant maxillary retrusion and downward rotation.

As might be expected, alternative treatment approaches can affect growth differently. Van der Beek and colleagues evaluated 61 children who had lip and/or palatal repair, including 35 children treated with lip adhesion and 26 children treated with preoperative orthopedics.⁶⁸ Maxillary retrusion was least for those whose hard palates had not been closed. Whereas delay of soft palate closure resulted in increased maxillary

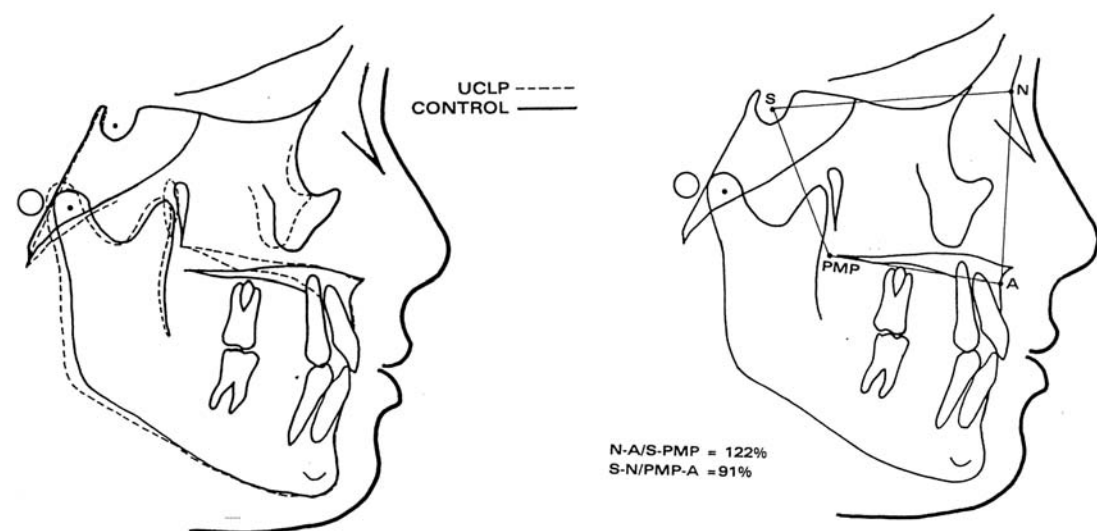


FIGURE 11-8 Comparison of the unilateral cleft lip and palate (UCLP) sample and the untreated controls.

length, postponement of lip closure produced a reduction of maxillary length.

Capelozza and colleagues evaluated adult males to assess the isolated effects of cheiloplasty and palatoplasty during growth.⁶⁹ They reported no differences between the lip repair only and lip and palate repair groups. However, the dentofacial morphology of both groups was different compared with the unoperated control group.

Levitt and colleagues matched 19 unilateral cleft lip and palate patients, who had lateral cephalograms available before and after secondary alveolar bone grafting (mean age 10.6 years), with a control group that had a similar treatment history except for having had no bone grafting.⁷⁰ They found no group differences in sagittal or vertical growth, suggesting that secondary bone grafting does not adversely affect maxillary growth. These findings are in contrast to the maxillary growth problems that occur following primary bone grafting.^{71,72}

Using 146 uni- and bilateral cleft lip and palate patients, Henkel and Gundlach compared 55 patients who received gingivoperiosteoplasty with 91 who did not.⁷³ They showed a growth disturbance with gingivoperiosteoplasty, a higher incidence of open bite, shorter upper jaws, and a higher frequency of cross-bite. Wood and colleagues, comparing patients with complete unilateral cleft lip and palate who had undergone primary cleft lip and nose repair with and without gingivoperiosteoplasty, reported contrary results.⁷⁴ Their 6-year follow-up of 20 patients indicated that gingivoperiosteoplasty produced a more uniform position of the hard palate and that there were no group differences in maxillary growth.

Comparing 7 children whose soft palates were repaired according to the Furlow procedure, with 7 children whose repair was according to the Widmaier-Perko procedure, Mommaerts and colleagues found no differences in transverse growth.⁷⁵ They showed slighter greater sagittal growth in the posterior maxilla in the Furlow group, which might have been related to less fibrotic contraction in the palate or less scar tissue in the muscle. The Furlow technique also produced a smaller transverse posterior cleft size.

Silvera and colleagues compared 11 children, who had been treated with a two-stage palatoplasty combined with the Hotz' plate, with 10 children treated with a one-stage palatoplasty.⁷⁶ Lateral and frontal cephalometric evaluations showed that the maxilla was more retruded and grew less in its posterior aspect in the one-stage group. Although longitudinal data were available (the patients had data at 6, 8, 10, and 12 years), the results were analyzed in a cross-sectional manner and their noncleft control group included only 11 children evaluated at 12 years, all of which

limited their ability to conclude that the two-stage palatoplasty in combination with the Hotz' plate had good effects on maxillary growth.

Compared with a two-stage palatal closure (30 patients treated according to Widmaier and Veau technique), a single-stage procedure (29 patients treated with Veau's pedicled flap) has been shown to produce less severe deficits in vertical and transverse midfacial growth, but similar horizontal impairment.⁷⁷

There are also suggestions that presurgical orthopedics, surgical experience, and time of palatal closure account for some of the variation in postsurgical outcomes. Roberts-Harry and colleagues showed significant differences in maxillary growth between two groups of children with unilateral cleft lip and palate; growth deficiencies were attributed to presurgical orthopedics, radical nasal corrections, and less surgical experience.⁷⁸ Joos, comparing two large groups of treated patients with unilateral cleft lip and palate, showed better midfacial growth in children who had midfacial muscle reconstruction, without orthopedic treatment, than in children who had postoperative orthopedic treatment.⁷⁹ Friede and Enemark showed that delayed closure of the hard palate in patients with unilateral cleft lip and palate produces fewer maxillary growth deficits and a better final result.⁸⁰

Potential Causes of Maxillary Growth Disturbances

Premature Synostosis of Sutures Preventing Midfacial Displacements

The evidence indicates that surgical insults to growing sutures do not have lasting effects. There is redevelopment of cranial sutural ligaments that have been surgically altered.^{81,82} Selman and Sarnat reported that the gross size and shape of rabbits' snouts were similar to controls, whether the frontonasal suture had been extirpated bilaterally or unilaterally.⁸³ Sarnat also evaluated the effects of complete surgical removal of the median and transverse palatine sutures and oral and nasal mucoperiosteum (essentially producing complete unilateral clefts) in young *Macaca* monkeys.⁸⁴ Whereas the surgically produced clefts persisted to varying degrees, no significant gross differences were noted in growth and development of the hard palate, maxillary arch, or maxillomandibular relationships. Strenström and Thilander also showed that sutural resection does not produce significant skeletal growth deficits.⁸⁵

Kokich and Shapiro transected the premaxillomaxillary suture and showed microscopically that it was patent 2 years postsurgery, and that the structure of its ligaments was similar to unoperated controls.⁴⁵ They also did not see premature fusion of the other, unoperated, sutures

(eg, zygomaticomaxillary, palatomaxillary, and pterygopalatine).

Importantly, for preexisting synostoses, the circumaxillary and intramaxillary sutures might be expected to have a major impact on postsurgical midfacial growth. This consideration is especially important for children with CAP syndromes, for whom synostosis of one or more cranial sutures is often a component of the syndrome. The possibility of existing synostoses should be considered as part of any diagnostic work-up of growing patients with severe midfacial growth deficiencies.

Damage to the Nasal Septal Cartilage

There is good evidence that surgical insult of the nasal septum results in growth deficiencies. Resection with the cartilaginous septum has been associated with an underdeveloped maxilla, a shorter snout, and malocclusions in experimental animals.⁸⁶⁻⁸⁸ After resecting large portions of the septum and associated mucoperichondrium in young growing rabbits, Sarnat and Wexler reported decreased growth in the snout, reversed incisor relations and over-eruption of the incisors.⁸⁹ The maxillary and premaxillary bones were smaller in the operated-upon animals, and the severity of deformity was proportional with the amount of septum resected. Follow-up studies suggested that the deformities observed after resection were due to a lack of growth rather than a lack of support by the nasal septum.^{90,91}

Siegel's work with primates also showed that resection of the septum influences midfacial growth, and that the effects depend on the amount of septum resected and the timing of resection during growth.⁹² Nanda and colleagues concluded that the midfacial growth retardation they produced in primates with Le Fort I osteotomies was probably related to nasal septal cartilage damage.⁴³

Importantly, Kokich and Shapiro sectioned the anterior portion of the nasal septum and posterior portion of the vomer, and disarticulated them from the nasal crest of the maxilla.⁴⁵ The dry skull preparations showed that the proximal and distal fragments of the vomer had reunited. They concluded that any detrimental effect on growth of the maxilla was temporary and had minimal effect.

Assuming that the decreases in AP growth seen postsurgically are related to the damage of the septal cartilage, surgeons have been advised⁹³ to use complete maxillary alveolar osteotomies, which require very little invasion of the nasal septum, in growing patients.^{94,95} Recommendation would be for the surgeon to either avoid the septum or transect and subsequently reapproximate the nasal septum when maxillary surgery is performed in growing children.

Inhibiting Effects of Soft Tissue (Scar Tissue, Wound Contracture, and Soft Tissue Stretching)

Of all the possible causes of midfacial growth disturbance, the inhibiting effects of scar tissue and wound contracture are perhaps the best documented. Raising mucoperiosteal flaps on the hard palate of dogs produced narrower dental arches^{96,97}; vestibular mucosal transposition flaps alone reduced growth on the operated side in rats⁹⁸; and periosteal resection produced marked skeletal reductions in rabbits.⁹⁹

Performing unilateral palatal surgery in beagle dogs, Kremenak and colleagues reported maxillary growth disturbances, which they attributed to wound contraction following mucoperiosteal surgery.^{97,100} Kremenak and Searles showed that elevated and repositioned palatal mucoperiosteal flaps in dogs produced irreversible deformation of the midfacial structures, due to restrictive influence of scar tissues and tissue contraction.¹⁰¹

Performing surgery on both sides of the palate in three groups of beagle dogs, Wijdeveld and colleagues concluded that palatal surgery had no effects on vertical or AP growth; transverse palatal growth was restricted and the amount of restriction was age dependent.¹⁰² During the surgery, a standardized elliptical soft tissue defect was created in the median region of the palate by excising a mucoperiosteal flap. Relaxation incisions were made adjacent to the posterior teeth, the mucoperiosteum was elevated, and the soft tissue defect was closed, leaving two areas of denuded bone adjacent to the dentition. The results showed significant (50%) reductions in maxillary width; maxillary length was significantly reduced only in the older experimental animals, indicating a potential for catch-up in the younger animals. Because their sample sizes were small, perhaps the most that can be said is that the palatal soft tissue surgery has an effect on subsequent maxillary growth, although the majority of growth potential is retained.

To study how the maxillary arch is constricted by mucoperiosteal denudation, Kim and colleagues evaluated the growth of 35 20-day-old rats, divided into control and experimental groups.¹⁰³ They showed that the scar tissues formed by denudation, which were tightly connected to both the palatal bone and teeth, restricted transverse palatal growth and inclined the molars medially. Medial inclination of teeth was demonstrated to be more important than inhibition of lateral growth for determining the constriction of the maxillary arch.

Surgical lip repair restricts the normal anterior displacement of the midface. Bardach and Mooney demonstrated maxillary growth restriction subsequent to lip repair in beagles with surgically produced cleft lip and palate.¹⁰⁴ Based

on a study of 35 rabbits evaluated over a 20-week period, it has been shown that lip pressures increase significantly after cleft lip repair.¹⁰⁵

It has also been shown that both the amount of surgery and the sequence of lip and palatal surgery can influence maxillary growth. Using two control and three experimental groups of 76 beagle dogs, it has been shown that simultaneous lip and palate repair produces more severe growth deformities than lip repair or palate repair performed separately.¹⁰⁶ Using 70 beagles, Bardach and colleagues showed that the sequence of lip repair first, and palate repair second, was less detrimental to maxillary growth than palatal surgery first or simultaneous lip and palate repair.¹⁰⁷

The effects of soft tissue stretching also cannot be disregarded. Kokich and Shapiro recognized that their primate experiments, in which they advanced the maxillas, might have produced substantial tension in the soft tissues.⁴⁵ They could not rule out stretching as a possible cause of the observed midfacial discrepancy. Soft tissue stretching, which might be expected to inhibit midfacial displacement over the short term, also has a number of potential long-lasting deleterious effects, including (1) scar tissue formation within the muscle that would prevent normal displacement, (2) nerve damage, (3) vascular compromise, and (4) altered biomechanical environment.

Owing to the magnitude of displacement that often occurs, the potential negative consequences of soft tissue stretching must be considered in any treatment plan for distraction osteogenesis.¹⁰⁸ A possible argument favoring distraction osteogenesis in growing children may be that the gradual movements are more readily adapted to in growing than in nongrowing individuals. Even though the surgical movements are not acute, the effects of distraction on the soft tissues remain to be clearly established.

Damage to Growing Structures that Secondarily Displace the Midfacial Skeletal Units

An early series of studies performed by Sarnat and Shanedling showed that orbital dimensions are dependent on the contents of the orbit.¹⁰⁹ They demonstrated a direct relationship between the lack of orbital mass (following evisceration or enucleation) and the subsequent lack of orbital development. The supraorbital process was smaller and less elevated, the zygoma was shorter, and the facial skeleton deviated towards the experimental side. Later, they showed that periodic intrabulbar injections of silicone in the growing rabbit increased orbital volumes significantly.¹⁰⁹ These and other similar experiments are important, because they demonstrate that the skeletal units grow in direct response to their associated nonskeletal tissue structures.

Mandibular Surgery

Clinical Studies

The early literature indicated that there were no clinically obvious growth effects when advancing the mandible with sagittal split osteotomies in growing children.^{50,111} Schendel, Wolford, and Epker reported the effects of mandibular advancements (5.4 mm) on 12 children treated between 8 and 16 years of age.^{112,113} The median follow-up period was 3 years 7 months. Although data were not provided, postsurgical growth was reported, and the Class I occlusions established during surgery were maintained. Their figures suggested that most of the mandibular growth that occurred was vertical, with little or no change in AP chin position. They concluded that advancement surgery could be done safely in children.

Epker and O'Ryan reported altered mandibular growth patterns in 15 growing patients evaluated approximately 4.5 years after advancement surgery.¹¹⁴ Three groups, categorized based on the presenting mandibular plane angles, were compared. They speculated that the different growth patterns might be expected depending on how the segments were surgically rotated and on the consequent postsurgical condylar loading patterns. However, these notions remain untested and should not be applied indiscriminately.

Huang and Ross evaluated 22 growing patients who had mandibular advancements.¹¹⁵ Their results showed severe growth disturbances following surgery, with the response being proportionate with the amount of correction. Patients who were advanced more than 10 mm showed condylar resorption, bony outgrowths in the posterior symphysis, and reductions in mandibular length. Cases that were advanced less than 9 mm had a milder response, but no clinically significant mandibular growth. In 15 (68%) of the cases, mandibular growth ceased after surgery, whereas 6 cases showed increases of less than 2 mm, and only 1 case demonstrated clinically relevant growth. Even though mandibular length did not increase, they did report an altered condylar growth direction that changed mandibular shape rather than length. These results have been criticized because (1) they were not based on a random sample of normal growers (4 had craniofacial anomalies and 2 had juvenile rheumatoid arthritis), (2) the landmark used to measure mandibular growth (intersection of the posterior surface of the symphysis with the inferior border of the mandible) could have been affected by resorption of the genioplasties, and (3) the sample had little growth potential.¹¹⁶ Although most of the children were past ages of peak velocity, they nevertheless retained considerable growth potential.

Snow and colleagues evaluated 12 patients, 12.2 to 15.9 years old at the time of surgery, who had been treated with surgical mandibular

advancement and followed up 3.1 years post-surgery.¹¹⁷ Of the 12 patients, 10 showed postsurgical mandibular growth. They reported that the amount of growth was approximately what would have been expected for the children's age, although no direct comparison with an untreated control group was made. The direction of postsurgical mandibular growth was entirely vertical and the chin did not come forward. They recommended that because of the lack of AP mandibular development, advancement procedures should not be performed in younger patients who have maxillary growth potential, unless extenuating circumstances prevail.

Our recent case-controlled study was designed to evaluate mandibular remodeling subsequent to superior maxillary repositioning only.⁴¹ Fifteen growing VME patients (12.8 years) were evaluated 1.6 ± 1.2 years prior to surgery and 4.0 ± 2.2 years postsurgery. Compared with matched untreated controls, there was no inhibition of mandibular growth postsurgically, even though there was a decrease in AP maxillary growth. Most importantly, we showed that the postsurgical changes in mandibular modeling and condylar growth indicated adaptive compensations for surgical repositioning and autorotation (Figure 11-9). The results also showed that growth was not normalized by early surgical impaction, because the vertical growth pattern displayed by these subjects was not changed. In this regard, it should be remembered that previous studies suggesting a normalization of postsurgical growth did not use matched controls, and subjectively evaluated postsurgical changes.^{37,38}

Experimental Studies

Nanda and Topazian, who compared 8 control and 7 experimental animals, reported that

mandibular growth was significantly less in the animals that had maxillary impaction than the controls.¹¹⁸ Subsequently, Nanda and colleagues showed that maxillary impaction and advancement surgery altered mandibular growth.⁴³ Based on 6 experimental and 8 control animals, advancement alone or advancement and impaction in combination produced a significant reduction in mandibular growth. The amount of reduction was proportionate with the reductions in maxillary growth.

Carlson and Ellis evaluated the growth of six juvenile *Macaca mulatta* monkeys following mandibular advancements.³⁶ Compared with untreated controls, the experimental animals' mandibular growth was not significantly different. The mandibles remained larger than the mandibles of the age-matched controls throughout the experiment. Interestingly, their data did suggest a relative reduction in AP displacement and an increase in vertical displacement of the mandible of experimental animals. Because the findings are limited by the sample sizes, the effects of surgical insult on postsurgical growth cannot be ruled out.

The animal literature shows that there is also a difference, albeit limited, in mandibular growth following mandibular surgery. Even maxillary surgery alone has the potential to affect mandibular growth. Further research is needed to more precisely predict and understand how surgery affects mandibular growth.

Conclusions

Surgery has definite, but highly variable, effects on mandibular and maxillary growth. Effects are to be expected, because all surgical interventions impose some degree of stress (cellular, physiologic, or biomechanical) and intentionally alter the system's equilibrium. Owing to the magnitude of developmental changes taking place, childhood and adolescence must be considered as critical periods during which individuals are especially susceptible to stress produced by surgery. Consequently, development adaptations to surgically induced stress are dependent on the patient's growth potential. Adaptations will also depend on the tissues involved and the extent to which their equilibrium has been disrupted. If growth processes are interfered with, then growth deficits or excesses should be expected, suggesting that developmental adaptations should be expected in most instances.

- The most consistent and pronounced effects on growth have been produced with maxillary surgery. Vertical growth does not appear to be inhibited by maxillary surgery. In fact, vertical growth shows little or no change following maxillary surgery, suggesting that surgery may not be effective in

"normalizing" vertical growth tendencies. Both the clinical and animal studies clearly demonstrate detrimental AP, and perhaps transverse, growth effects following maxillary surgery.

- The various directions of maxillary growth are not equally affected. AP dimension appears to be most susceptible to insults, although vertical and transverse growth deficiencies have also been reported.
- The nature of the presenting problem, the type of surgery performed, the magnitude of surgery, and the timing of surgery have all been shown to affect postsurgical maxillary growth.
- The potential causes of the growth deficiencies include scarring/contracture (which poses the biggest potential problem), surgical insult to the nasal septum, and soft tissue stretching.
- How surgery affects growth will depend on the timing of surgery and the patient's growth potential. To predict the potential effects, the surgeon must understand the mechanisms that normally produce growth. Most importantly, any interference with the normal inferior, anterior, and transverse displacements of the midface might be expected to produce lasting growth deficiencies.
- Mandibular growth is also affected by early surgery. Growth patterns can be altered and growth may be restricted.
 - There are indications that mandibular surgery decreases AP mandibular growth. There are also suggestions that maxillary surgery alone, without concomitant mandibular surgery, can reduce AP mandibular growth.
 - Vertical mandibular growth does not appear to be altered by early surgery. Based on our knowledge of normal growth, excessive surgical movements (especially vertical) in the posterior aspect of the mandible might be expected to produce larger developmental adaptations.
 - Early surgery does not appear to normalize growth patterns of hyperdivergent patients.
- Surgical procedures should minimize interferences with normal growth processes.
 - Growth centers of endochondral bone formation should be avoided. Severe and long-lasting detrimental growth effects have been produced by surgical damage to the septal cartilage.
 - Scar tissue contractures can restrict or inhibit normal displacements of the bony elements. They should be expected

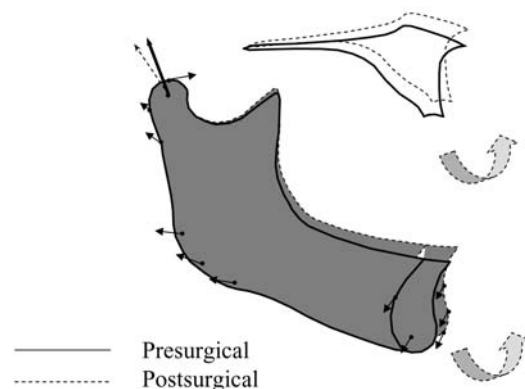


FIGURE 11-9 Maxillary impaction and the resultant mandibular repositioning. Arrows represent the direction of the adaptative modeling expected for the mandible.

- to limit growth and produce modeling changes.
- Stretching of soft tissues beyond the physiologic limits may produce lasting insults that could limit future growth potential and alter remodeling patterns.
 - Any positional changes of structures might be expected to alter their biomechanical environment and produce remodeling changes as equilibrium is reestablished.
 - Because response potential is directly related with growth potential, surgical treatment plans of growing patients should:
 - Consider differences in relative growth potential between structures (within individuals) when predicting proportionate versus disproportionate growth
 - Incorporate individual differences in growth potential

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Surgical Orthodontics in Mandibular Widening

César A. Guerrero, Gisela I. Contasti, Aura Marina Rodríguez and Fabrianne Figueroa

Transverse mandibular deficiency is a common clinical finding in dentofacial deformities treated by both orthodontists and surgeons.¹⁻³ Usually, this problem is managed with orthodontic dental compensations, interdental stripping, bicuspid, or single-incisor extractions to create arch space, changing the anterior teeth axial inclination, or combining the treatment with surgical procedures.

Distraction osteogenesis appears as a new modality to progressively stretch the bone and the soft tissue envelope. This surgical philosophy treats the deformity using the biologic principle of tension and stress to create enough bone and surrounding soft tissues to ideally align the dental structures on the jaws, avoiding dental compensations, dental extractions, and/or periodontal problems.

Traditional orthognathic surgery continues to solve the majority of the dentofacial deformities in our patients^{4,5}; however, there is a group of patients who would benefit more from the use of distraction osteogenesis to accurately correct their deficiencies, with long-term stable outcomes. This chapter outlines the importance of the three-dimensional evaluation, the indications for distraction osteogenesis, combined orthognathic surgery, orthodontics-surgery sequence, the use of different appliances, and surgical techniques.

Mandibular Widening

Clinical Indications and Selection of Patients

Esthetics has taken outrageous importance in our patients, who look for a beautiful young appearance that lasts over time, ideal dental alignment, wide smiles, an adequate tooth to lip relationship, a small biprotrusion that maintains a fresher look over the years, and avoiding dental extractions while correcting dental crowding.

Since our first case in 1987, distraction osteogenesis to widen the mandible has become very popular in the treatment of mandibular transverse deficiencies, showing stable long-term results and avoiding the incisor recrowding observed in compensating orthodontics (Figures 12-1 through 12-7).⁶⁻⁸

The indications for mandibular widening include the need to change a narrow V-shaped mandible to a U-shaped mandible, the need to create space without dental extractions when severe mandibular crowding and a compromised facial profile exist, uni- or bilateral scissors bite (Brodie's syndrome), maxillomandibular transverse deficiency (tunnel smile, crocodile's bite), impacted anterior teeth to allow natural or forced eruption, re-treatment after bicuspid extractions, and congenital missing teeth.⁹⁻¹²

Systematic Description of the Three-Dimensional Problem

The severe crowding is usually part of a micrognathia, which includes a three-dimensional deficiency in growth, with skeletal and dental problems. Because the functional matrix dictates

the development of both the maxilla and the mandible, most of the skeletal Class II and narrow mandibles will also present problems in the maxilla. The clinician must decide whether distraction osteogenesis or traditional orthognathic surgery is indicated to correct the sagittal deficiency based on the amount of movement required anteroposteriorly and other specific patient considerations for mandibular lengthening.¹³⁻¹⁵

Traditionally, dental crowding was treated by dental extraction and compensatory orthodontics, obtaining unstable results, periodontal problems, and/or extremely narrow dental arches with tunnel smiles.¹⁰ Distraction osteogenesis brings the opportunity to align the teeth in an adequate bony base to avoid dental compensations, periodontal problems, and dental extractions, improving smile width and eliminating the sinking lip appearance in the profile view secondary to extractions.¹⁸⁻²³

Presurgical Clinical Assessment

Treatment planning is the most important step and should be done in conjunction with the

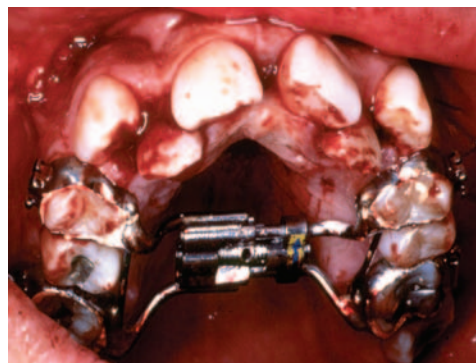


FIGURE 12-1 On April 10, 1987, the first mandibular widening by distraction osteogenesis. Maxillary widening was also accomplished. Observe the 2 mm intraoperative activation at the midlines. Minimal incision and desperiostization to improve distraction healing.

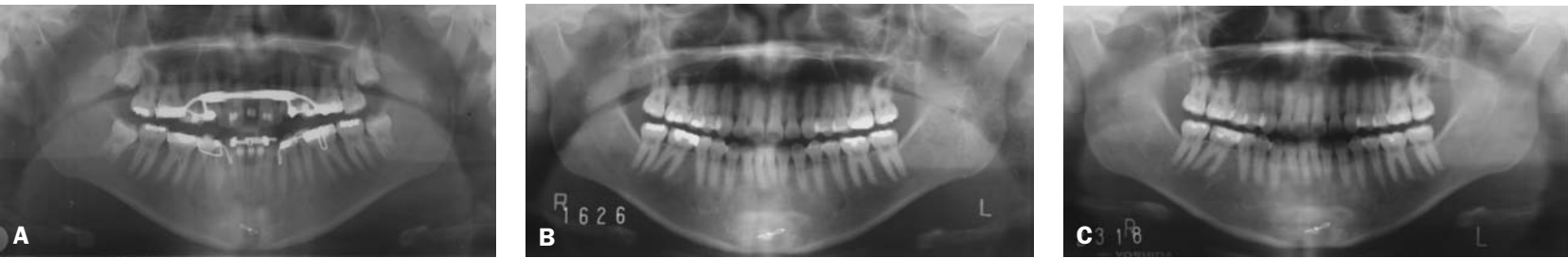


FIGURE 12-2 Panoramic radiographs. *A*, After the activation period, note the radiolucent distraction chamber area and the bracket placed to hold the plastic tooth in the interdental space created. *B and C*, Immediately and long term after distraction and orthodontic treatment. The distraction area has the radiographic appearance of surrounded bone.

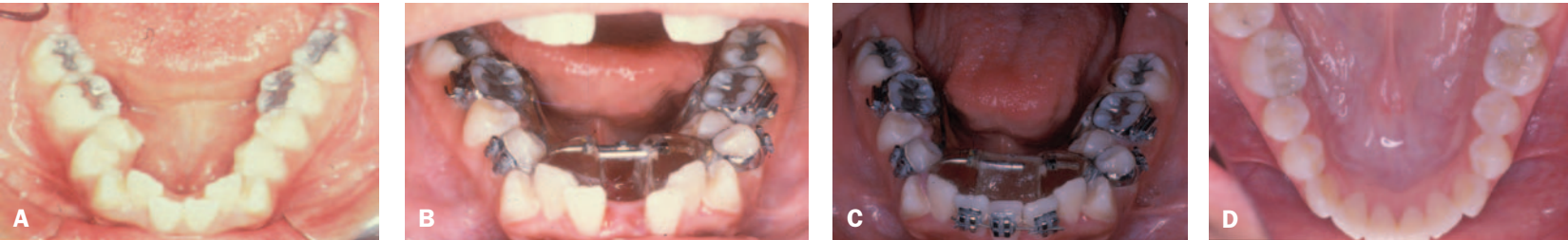


FIGURE 12-3 Mandibular widening sequence. *A*, Observe the severe dental crowding in the preoperative inferior occlusal view. *B*, Incisor separation after complete activation. *C*, A plastic tooth is placed with brackets to fill the new interdental space. This prevents teeth from moving too rapidly into the distraction chamber during the consolidation period. *D*, Proper teeth alignment with no dental extractions.

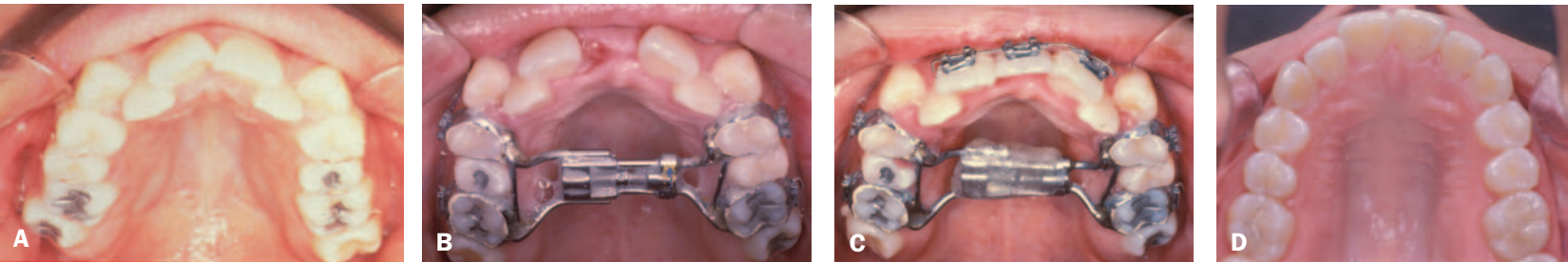


FIGURE 12-4 Simultaneous maxillary widening was carried out. *A*, Preoperative dental crowding. *B and C*, After complete Hyrax activation, acrylic is placed on the distractor screw and the patient advances from a liquid to a soft diet. The plastic tooth is used for esthetic purposes and to prevent teeth from “walking” into the distraction site as transeptal fibers stretch. *D*, Final superior occlusal view; no extractions.



FIGURE 12-5 Before and after right dental views. Class I occlusion was obtained.



FIGURE 12-6 Left dental views before and after distraction osteogenesis was used to widen the maxilla and the mandible.

dental model study and occlusograms to choose the type and size of distractor to be used in a particular case.

The patient must be evaluated by the dental team as any surgical patient, and if crowns and bridges are needed, the patient would go to surgery with the temporary ones holding the definitive prosthesis until the brackets are removed at the end of the surgical-orthodontic treatment.

Dental Model Analysis

The amount of expansion required depends not only on the amount of crowding but also on



FIGURE 12-7 Frontal dental views after bracket removal and 19½ years later show long-term stable occlusion.

orthodontist; it is based on systematic clinical, radiographic, and dental model evaluations to assess the problem list and plan the surgery according to it. The radiographic evaluation includes panoramic, posterior-anterior, and lateral cephalometrics to evaluate asymmetries and discrepancies in the anterior-posterior dimension that should be corrected in the same surgical intervention (Figure 12-8), and a periapical radiograph is used to determine the best interdental osteotomy location to warrant enough bone at both osteotomy sides.^{24,25} An ideal osteotomy site could be achieved presurgically with orthodontics to improve dental inclinations and increase the interradicular space. The osteotomy design is related to the osteotomy site, and the three-dimensional evaluation and the exact amount of expansion required must be assessed with the

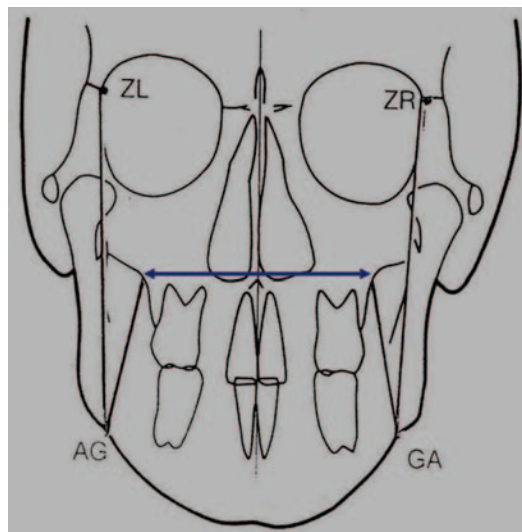
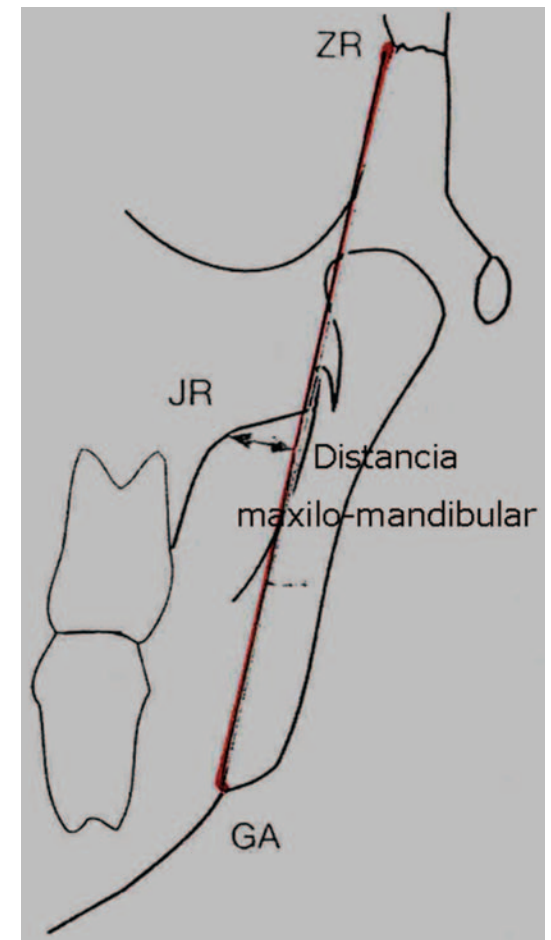


FIGURE 12-8 Evaluation of maxillomandibular transverse discrepancies. Effective maxillary width (JL-JR) is the distance between the right and left jugal points located at the intersection of the tuberosity outline and zygomatic buttress. Effective mandibular width (AG-GA) corresponds to the distance between antegonial points situated at the lateroinferior margin of the antegonial protuberance. To assess transverse discrepancies, frontolateral facial lines are traced bilaterally from the medial margins of the zygomatic-frontal sutures to the ipsilateral antegonial points. The distance from jugal points (JL and JR) to the ipsilateral frontolateral line along the effective maxillary width line is measured. Each side is evaluated independently, and if it measures > 10 mm, a transverse discrepancy exists.



several variables to be considered, such as available versus required space, axial inclination of the inferior incisors (1 MPA = 90°), deep bite or a severe curve of Spee, intermolar width, and the size and shape of the inferior incisors.

The decision to use a bone-borne or a tooth-borne appliance is made based on dental model evaluation, assessing the available lingual transverse space and molar inclination to allow appliance insertion (Figure 12-9). Also, periodontal status must be evaluated with radiographs to choose adequate anchorage teeth.

The total amount of distraction is calculated using the occlusograms to analyze the required space and tooth size discrepancy (Figure 12-10).



FIGURE 12-9 Enough lingual transverse distance needs to be present to use the tooth-borne appliance. The Hyrax must be passively adapted and remain in position until consolidation occurs.

It is very important to correct the maxillary dentition before the occlusogram is made because the mandible will be expanded to fit within the confines of the maxillary arch. A lateral cephalometric radiograph is used to evaluate the incisor inclination and dental models to measure the curve of Spee.

Soft and Hard Tissue Clinical Analysis

From the biologic standpoint, there should be a healthy periodontium with at least 1 mm of bone protecting the roots on either side of the osteotomy. Lack of enough bone at the osteotomy level can lead to delayed healing and periodontal defects; an adequate volume of vital bone is required to create new bone.²⁴ The osteotomy design and site are selected based on the bone quantity between roots, inclination of the teeth, curve of Spee, and periodontal status.

Surgical Planning

Once the required expansion is determined, considering the dental crowding, incisor angulation, curve of Spee, and intermolar distance, it must be understood that in mandibular widening, the amount of activation does not correspond to the total intermolar distance augmentation, differing from maxillary widening where the amount of activation produces the same amount of intermolar distance increase. In the mandible, the arch

widens more at the symphyseal level than it does at the intermolar area.²⁶ Del Santo and colleagues performed a long-term study in 20 of our patients, concluding that for a 7 mm activation, there is a 7 mm intercanine transverse increase, 5 mm at the first intermolar level, 3 mm at the intersecond molars, and 0.9 mm between the two mandibular condyles.²⁷ This indicates that the widening is achieved in full range in the midline, decreasing while going back toward the molars, with an increase in the intercondylar distance of only 0.9 mm (Figures 12-11 and 12-12).

After completing the required activation, a canine and premolar crossbite, edge-to-edge first molar bite, and normal second molar occlusion will develop, and as the orthodontist closes the anterior gap, the lateral crossbite is corrected. The average activation for the 20-patient group studied by Del Santo and colleagues was 7 mm, but the final intercanine width increase was only 2.88 mm after orthodontic movement to close the distraction gap (Figure 12-13).²⁷

If the amount of mandibular widening required to align the incisors and correct the curve of Spee creates a molar lateral crossbite, maxillomandibular widening must be planned to accommodate the transverse relationship at the first molar region and align the maxillary and mandibular incisors.²⁸

The vertical osteotomy site must be planned at the most convenient interdental space where

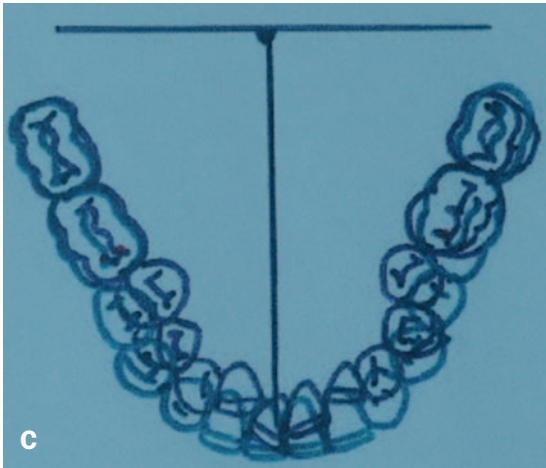
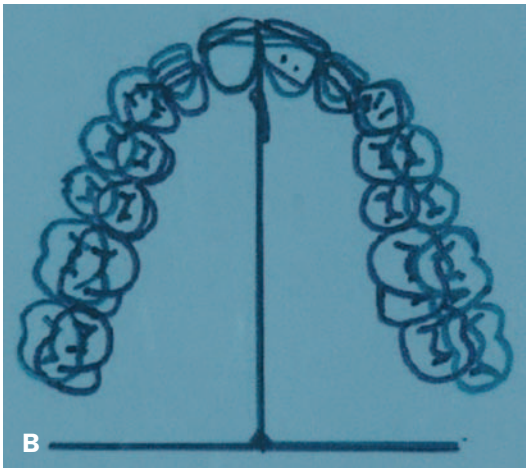
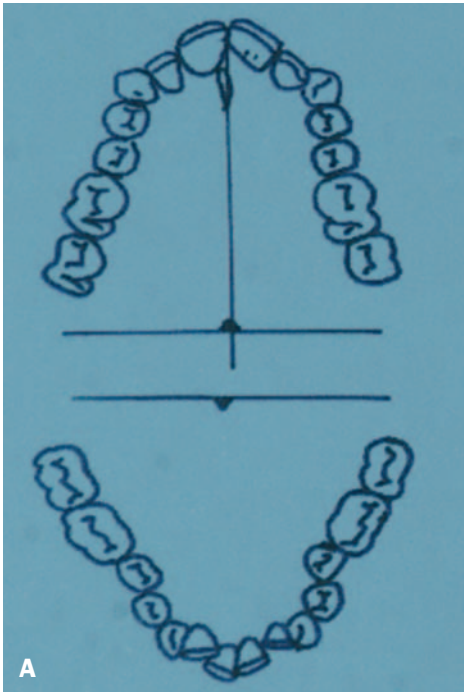


FIGURE 12-10 Transverse mandibular deficiency. A, Individual dental arch analysis demonstrating severe mandibular crowding and a V-shaped mandibular arch. The need for mandibular widening is obvious to avoid dental extractions and transform the V-shaped to a U-shaped mandible. B and C, The occlusograms are used to calculate the amount of expansion required to solve the dental crowding. Also, the need for simultaneous maxillary expansion is also assessed based on the final mandibular intermolar augmentation.

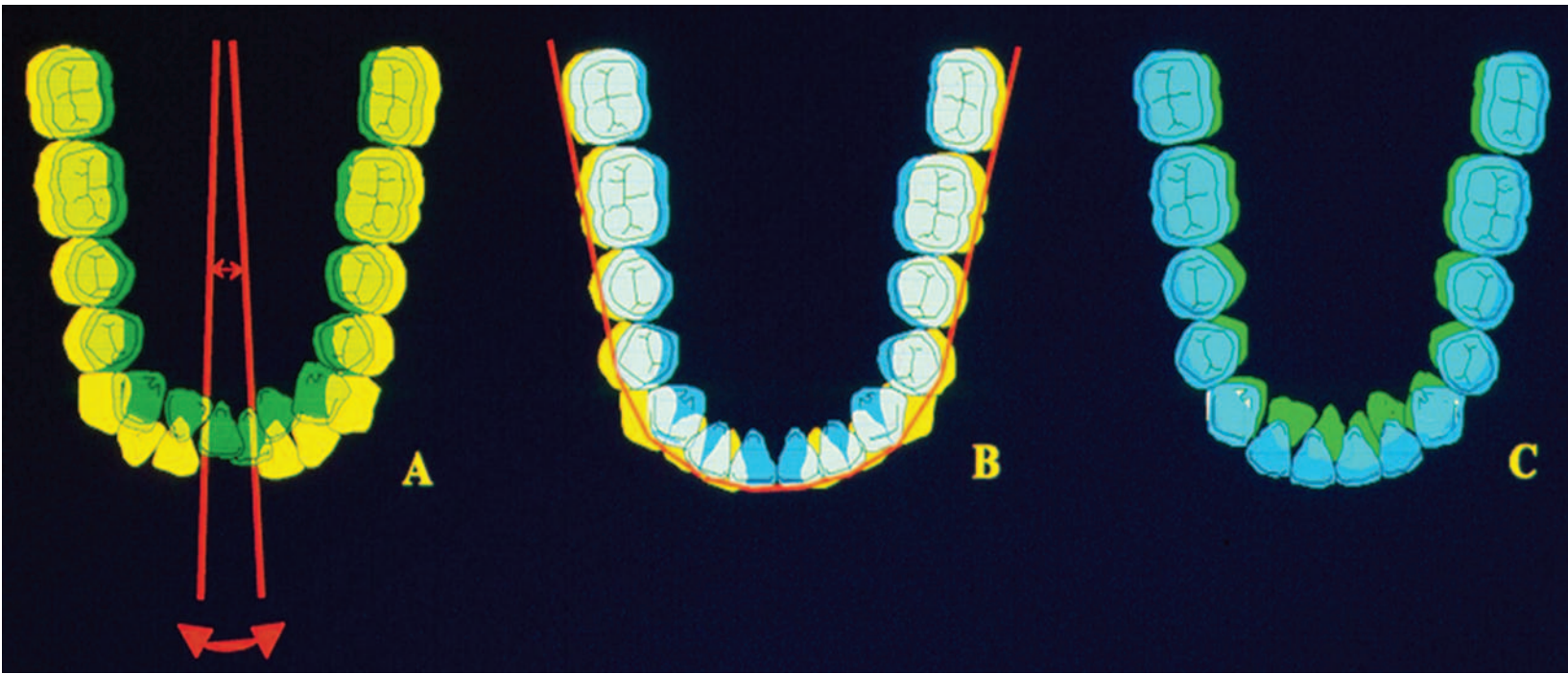


FIGURE 12-11 Del Santo and colleagues studied 20 of our mandibular widening patients to evaluate dental changes during mandibular widening.²⁷ A, Before distraction (green) and postactivation (yellow). Distraction is greater in the anterior than in the posterior area. B, Postactivation (yellow) and after orthodontic movements to align the teeth (blue). A 7 mm activation produces a 7 mm intercanine increase, a 5 mm first intermolar augmentation, and a 3 mm second intermolar expansion. C, Net changes preoperatively (green) to postdistraction orthodontic treatment (blue).

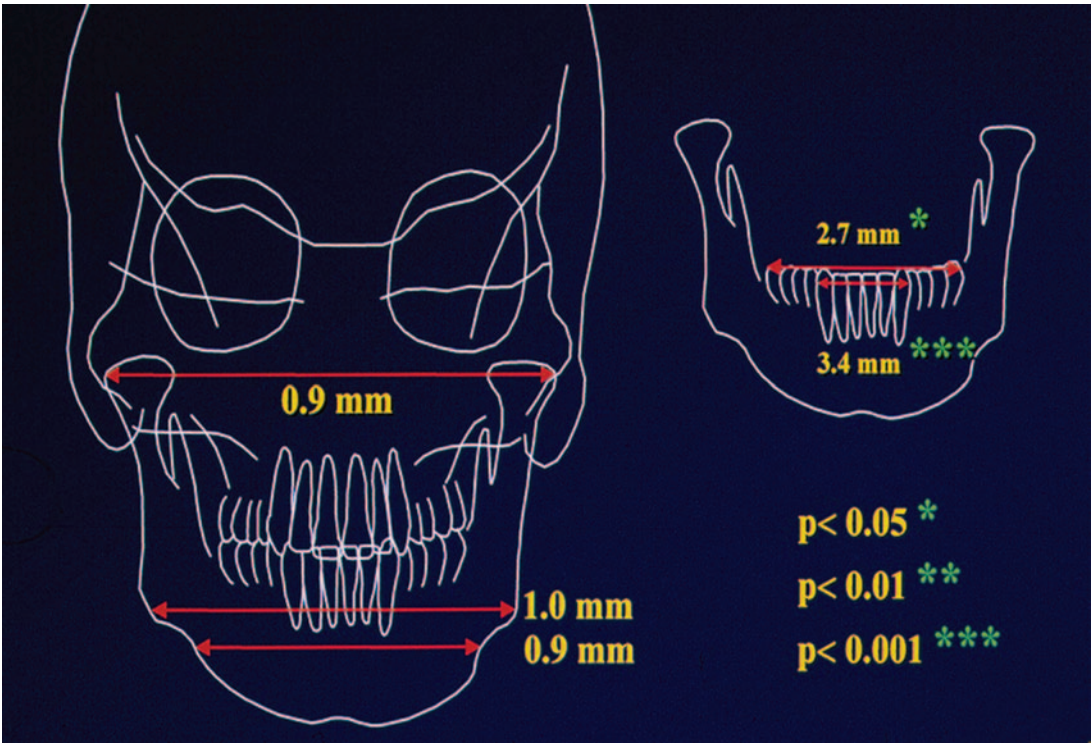


FIGURE 12-12 While widening is achieved in full range at the midline, it decreases as it goes back toward the molars, with an intercondylar increase of only 0.9 mm.

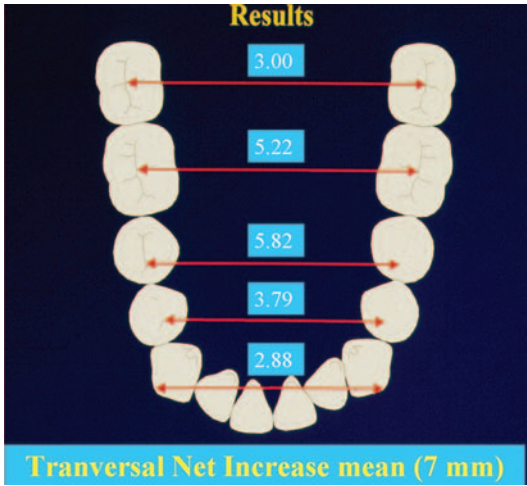


FIGURE 12-13 After a 7 mm mandibular widening, the final intercanine width increase reduces from 7 to only 2.88 mm after orthodontic movement to close the distraction gap is achieved.

sufficient bone is encountered, but at the inferior border of the mandible, it is mandatory that the osteotomy ends at the midline to avoid postdistraction asymmetry development (Figures 12-14 through 12-16).^{29,30} In major transverse expansions, the chin should be carefully evaluated, considering its preoperative shape and size to avoid an undesired extremely wide chin, altering the facial harmony, especially in the female patient

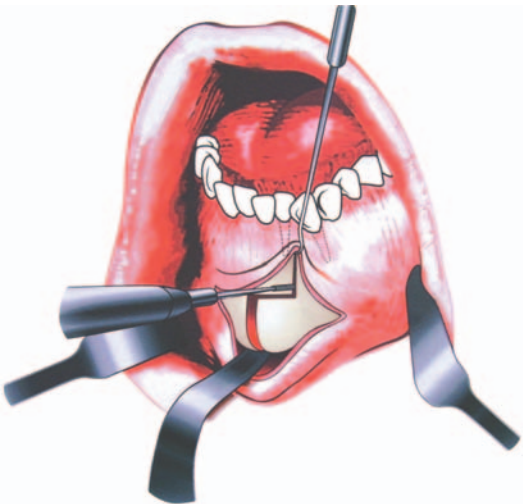


FIGURE 12-14 When the interdental osteotomy site is chosen off the midline, a step-osteotomy design starting at the midsymphyseal area is done to avoid facial asymmetries after distraction. Note minimal periosteal elevation and horizontal osteotomy location at least 5 mm away from dental apices to preserve teeth vitality.

(Figure 12-17). In those cases, a combined genioplasty is indicated to preserve the original chin appearance.

Presurgical orthodontics includes the following: complete upper arch alignment and leveling, the teeth are desrotated, diastemas are closed, molars are verticalized, and an ideal maxillary curve of Spee is obtained.²⁸ Once the maxillary teeth are ideally positioned, a final diagnosis and



reevaluation are made to change the mandibular arch to the new maxillary alignment. The lower-arch dental movements are restricted to obtain an interdental space to perform the osteotomy without damaging the dental roots.

The orthodontist evaluates and selects the best appliance according to the available lingual transverse space and incisor and molar inclination to allow device insertion, considering the amount of widening required.

In our experience, the tooth-borne lingual Hyrax appliance has been extensively used for mandibular widening since its first use in 1987, despite the difficult patient's hygiene, impingement of the tongue, inadequate access for activation, and the fact that it could be dislodged during the surgery (see Figures 12-3 and 12-9). This orthodontic appliance makes the surgery easier and lessens costs.

Since the tooth-borne device is a custom-made appliance, the shrinkage that the bands suffer in the welding process must be taken into account. The bands should fit loosely before the welding process so that the Hyrax may fit under the equator of the anchorage teeth, usually first premolars and molars, in a passive manner, avoiding appliance displacement at the time of surgery or canted occlusal planes with unilateral open-bite development.

The bone-borne intraoral device is also widely used, especially in severe crowding and excessive teeth lingual inclinations. Considering its versatility, its buccal fixation does not interfere with tongue function and it is easy to activate; however, it is more expensive than the tooth-borne device. When using this alternative, the appliance is presurgically adapted to the dental model after drawing the roots of the anterior teeth and the osteotomy line using radiographs as a reference to avoid injuring the roots of the teeth during surgery. The anchorage teeth, usually the canines, need to support distraction forces and are chosen based on periodontal status. The distractor rod needs to be parallel to the occlusal plane to avoid unilateral open bites.³²

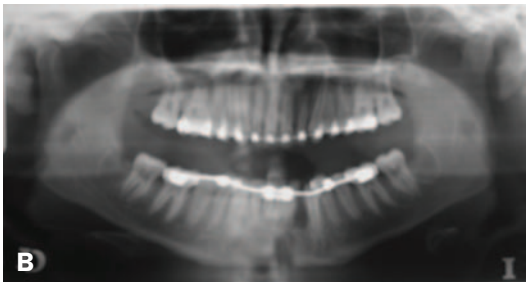
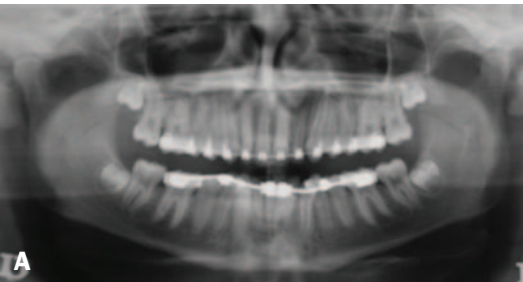


FIGURE 12-15 A, Preoperative panoramic radiograph with a dental-borne appliance in position. The osteotomy site chosen was between the left lateral incisor and canine because a good amount of interdental bone was present. B, Panoramic radiograph after activation, observe the distraction chamber with two portions, one at the midsymphyseal area and the other one between the left lateral and canine.



FIGURE 12-16 A and B, Mandibular widening using a single-screw tooth-borne device on the buccal. This type of appliance is more comfortable for the patient, avoids tongue impingement, is easy to activate, and eases oral hygiene. C, Dental alignment with no dental extractions.



FIGURE 12-17 A and B, A 19-year-old female with maxillomandibular transverse deficiency (crocodile's bite). C, Frontal view after maxillomandibular widening was performed. Compare the chin size and shape pre- and postoperatively and observe the undesired strong chin obtained after a 12 mm mandibular widening. This effect is avoided by combining a genioplasty osteotomy in the same surgical procedure to maintain the shape and size of the chin while widening of the alveolar process occurs.

More recently, single-screw devices welded to orthodontic bands in the first premolars and first molars have been placed in the buccal or lingual aspect of the mandibular teeth pre-operatively, being much easier to activate than the traditional Hyrax appliance (see Figure 12-16). This latter technology facilitates the patient's hygiene, it is better tolerated and is as inexpensive as the conventional Hyrax.

Special attention must be given to the passiveness of the tooth-borne appliances and the parallelism to the occlusal plane of the bone-borne devices to avoid inclination of mandibular segments that will result in asymmetric bone movements and consequent unilateral open bites and canted mandibular planes.³²

The device must be selected, either confectioned by the orthodontist (tooth borne) or adapted to the dental models by the surgeon (bone borne), before the surgery.

Considerations

- The interdental osteotomy must be planned using periapical radiographs, choosing the osteotomy site where enough bone is present at both sides of the cut.²⁴ If there is no ideal site, presurgical orthodontics must be performed to create enough interradicular space.

Most patients will require some type of chin surgery, including changes in the vertical, anterior-posterior, and/or lateral dimensions to obtain an ideal functional and esthetic result.³⁰ In some cases, the genioplasty is indicated to prevent widening of the chin, leading to non-esthetic results, especially in the female patient or when major mandibular widening is required (> 12 mm) (see Figure 12-17). The combination of both procedures provides several advantages, including single surgical invasion, less time taken away from school or work, cost reduction, and faster psychological adaptation.

When a genioplasty is also intended, the gap left at the inferior border of the vertical cut is greater than at the crestal level to ensure bony separation in the activation period. This maneuver is accomplished using an instrument within the vertical cut at the inferior level (where it reaches the horizontal genioplasty osteotomy) to separate the bony segments 5 to 6 mm while the fixation wires for the chin are tightened (Figures 12-24 and 12-31). The wires are used for fixation with minimum periosteal detachment and they are malleable enough to allow distraction device activation.

The tooth-borne appliances should not be forced into position; otherwise, when the osteotomy is carried out, rotation of the mandibular

segments with consequent unilateral open-bite development or appliance dislodgment will occur. Having a bone-borne appliance in the table will be helpful in these situations. When dislodgment occurs, a bony wire is used to temporarily unite both mandibular segments while the distractor is adapted and fixated, to avoid temporomandibular joint injury. To prevent loosening of the tooth-borne appliance, all other procedures planned for that surgical phase should be performed first to conclude with the mandibular widening.

Surgical Procedure

Midsymphysal Widening

Incision and Exposure

The incision is made 4 to 6 mm labial to the depth of the mandibular vestibule through the orbicularis oris muscle. After the muscle is transected, the dissection is directed obliquely through the mentalis muscle until contact with the mandibular symphysis is achieved. The periosteum is responsible for the distraction chamber healing and must be carefully reflected inferiorly to the lower border of the mandible, placing a small channel retractor to protect it throughout the osteotomy procedure. After the osteotomy is carried out from the inferior border up to the apices, the soft tissue between the mandibular

central incisors is carefully reflected superiorly to the alveolar crest and a skin hook is used to retract and protect the soft tissues while the interdental osteotomy is completed (Figure 12-18).^{24,28,33}

Osteotomy

With the channel retractor in position protecting the periosteum, a vertical osteotomy is made under abundant irrigation to maintain temperature within physiologic limits, ensuring vital bone for distraction. A reciprocating saw blade is used to osteotomize the midsymphyseal area, starting at the inferior border of the mandible through the labial and the lingual cortices and continuing to the interdental space between the apices of the mandibular incisors. The rest of the osteotomy is continued with a surgical #701 bur and a straight handpiece in a monocortical fashion through the labial plate of the mandible up to the alveolar crest, also under abundant irrigation to avoid damaging the teeth or the bone (Figure 12-19). No attempt is made to use the saw or the bur between the roots of the teeth. Once again, it is mandatory to have enough bone at the interdental osteotomy site.

If a bone-borne device is to be used, it must be fixated before the osteotomy is completed. The upper arms of the prebent bone-borne appliance are wired with a 0.024-inch gauge wire to the anchorage teeth, and a 2 mm transmucosal bicortical screw is used on each side to fixate the lower arms, in an oblique fashion at least 5 mm away from the teeth. Acrylic is placed over the wires around the teeth to provide more rigidity

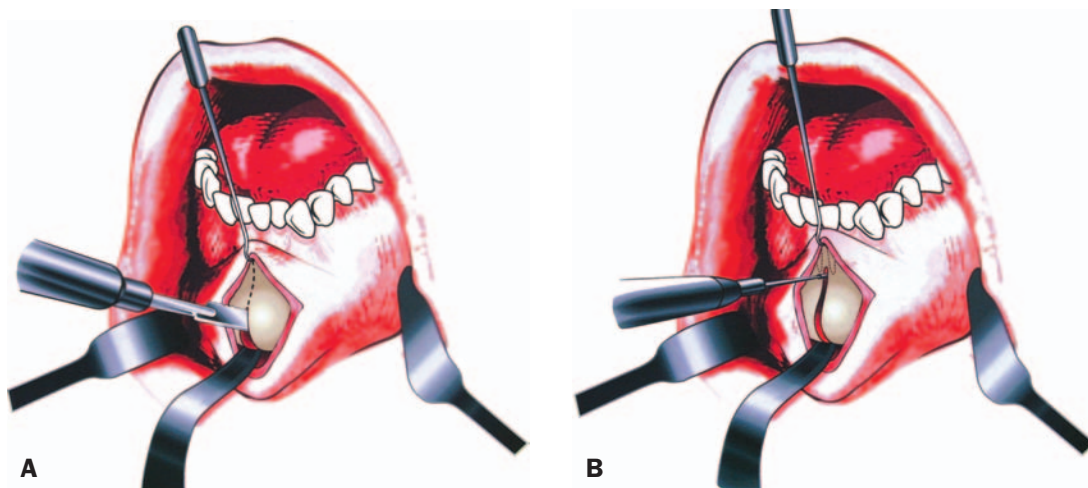


FIGURE 12-19 A, A bicortical osteotomy from the inferior border of the mandible to the interapical space is performed with a reciprocating saw, under abundant irrigation and with the retractors in position, protecting the soft tissues. B, A #701 bur is used only in the buccal cortex between the dental roots up to the alveolar crest with the skin hook in position.

(Figure 12-20). Before the last bicortical screw is positioned, special attention should be given to the parallelism between the major screw and the occlusal plane to ensure that the distraction vector is adequate, avoiding asymmetries and unilateral open-bite development during distraction.

The final sectioning is done with a mallet and a spatula osteotome, protecting the lingual alveolar aspect with the forefinger at all times to avoid tearing of the lingual soft tissues (Figure 12-21). When using a tooth-borne device, excessive pressure on the mandible should be avoided to

prevent displacement of the Hyrax, which is usually cemented to the mandibular teeth by the orthodontist 1 to 2 days prior to surgery.

Intraoperative Distraction

Once the vertical osteotomy is completed, either the bone-borne or the tooth-borne appliance is activated to produce a 2 mm immediate expansion of the mandibular arch. The quality of the gingival tissues will determine the amount of expansion feasible intraoperatively; excessive blanching of the interdental tissues makes it



FIGURE 12-18 The periosteum is reflected inferiorly to the lower border of the mandible, and a small channel retractor is placed to protect the soft tissues during the osteotomy. The soft tissue between the mandibular central incisors is carefully elevated to the alveolar crest, and a skin hook is used for retraction and protection.

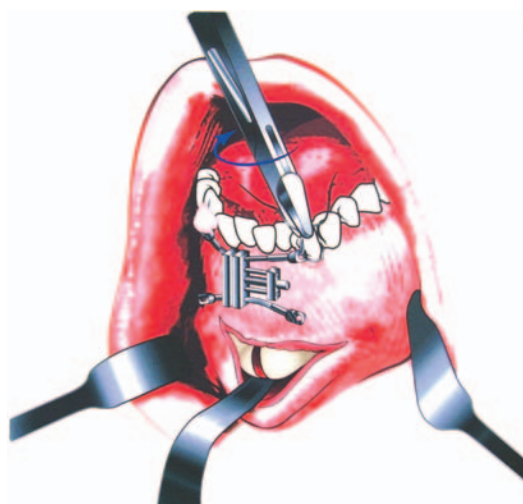
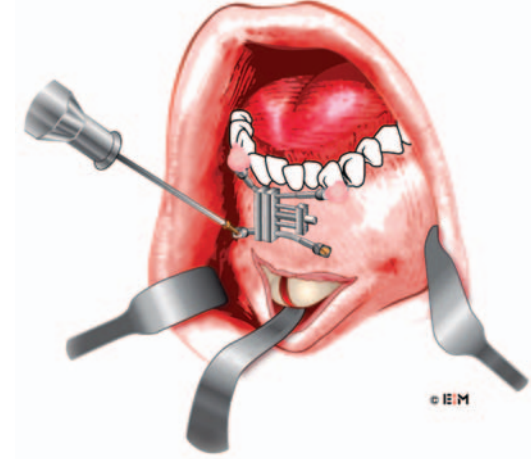


FIGURE 12-20 If a bone-borne appliance is to be used, it must be fixated before completing the osteotomy. The upper arms are wired to the anchorage teeth, placing acrylic to improve rigidity, and the lower arms are transmucosally screwed to the bone. The distractor screw needs to be parallel to the occlusal plane to avoid unilateral open bites.



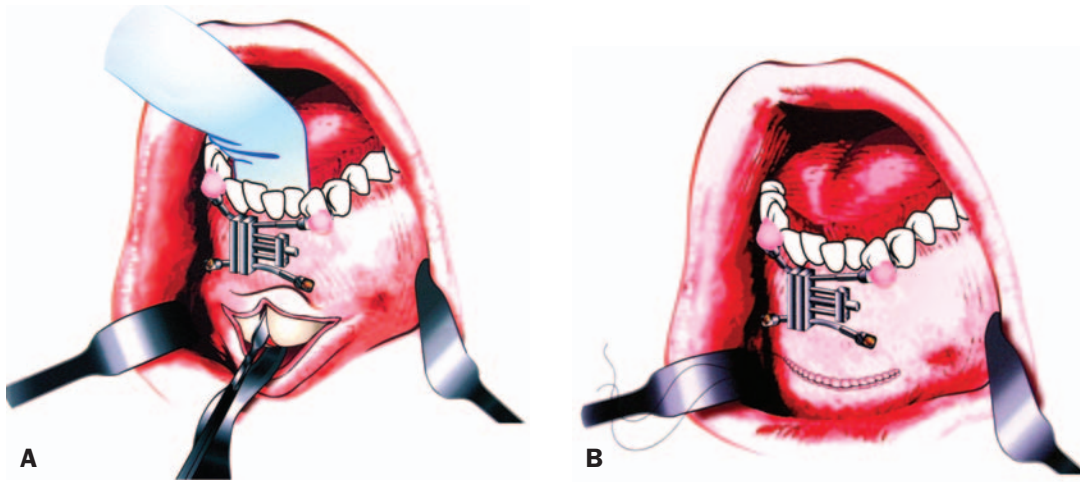


FIGURE 12-21 A, With the appliance in position and the forefinger protecting the lingual soft tissues, a spatula osteotome is used to complete the osteotomy. B, A three-layer closure with watertight mucosa closure to avoid food and saliva contamination.

Once the soft tissues have been properly reflected, a channel retractor is placed through a tunnel underneath the mental nerve to the level of the first molar, reference marks are made, and a reciprocating saw is used to perform a bicortical osteotomy at the inferior border of the mandible starting at the first or second molar region toward the symphyseal midline, 5 mm away from the dental apices.

The surgeon's forefinger is used externally to avoid damaging the soft tissue as the saw goes through the bone on the lingual. The use of a mallet and chisel or instruments to down-fracture the inferior bone segment is to be avoided because, usually, there will be incomplete irregular borders of the mandible fracture, increased bleeding, and postsurgical edema.

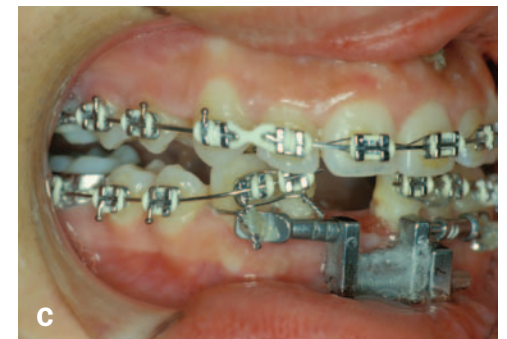


FIGURE 12-22 A and B, Midsymphyseal mandibular widening. Observe central incisors walking into the distraction site. C, Mandibular widening between the right central and right lateral incisors. Observe a simple 0.026-inch gauge wire uniting the brackets of the right canine and right lateral incisor and the brackets of both central incisors to prevent "walking" teeth.

necessary to reduce the initial activation to 1 to 1.5 mm to avoid periodontal problems and compromising the distraction process. At this point, a 0.026-inch gauge wire could be used to unite each central incisor to the consecutive lateral incisor or canine to prevent the teeth from "walking" into the distraction site owing to transseptal fibers stretching during the activation period (Figure 12-22).³⁰

Once the osteotomy and surgical activation have been performed, periosteum, muscle, and mucosa wound layers are meticulously closed using a 3-0 chromic suture.

Combined Genioplasty and Mandibular Widening

When the patient would benefit from a genioplasty, the two procedures are performed at the same time (Figures 12-23 through 12-29). In our series, 75% of the patients underwent simultaneous widening with some type of genioplasty.



FIGURE 12-23 A, A 14-year-old female patient with left condylar hyperplasia, anterior-posterior maxillary deficiency, vertical excess of the chin, and maxillomandibular transverse deficiency with ectopic canines. B, Three-year postoperative full facial view, with adequate balance, symmetry, and tooth to lip relationship.

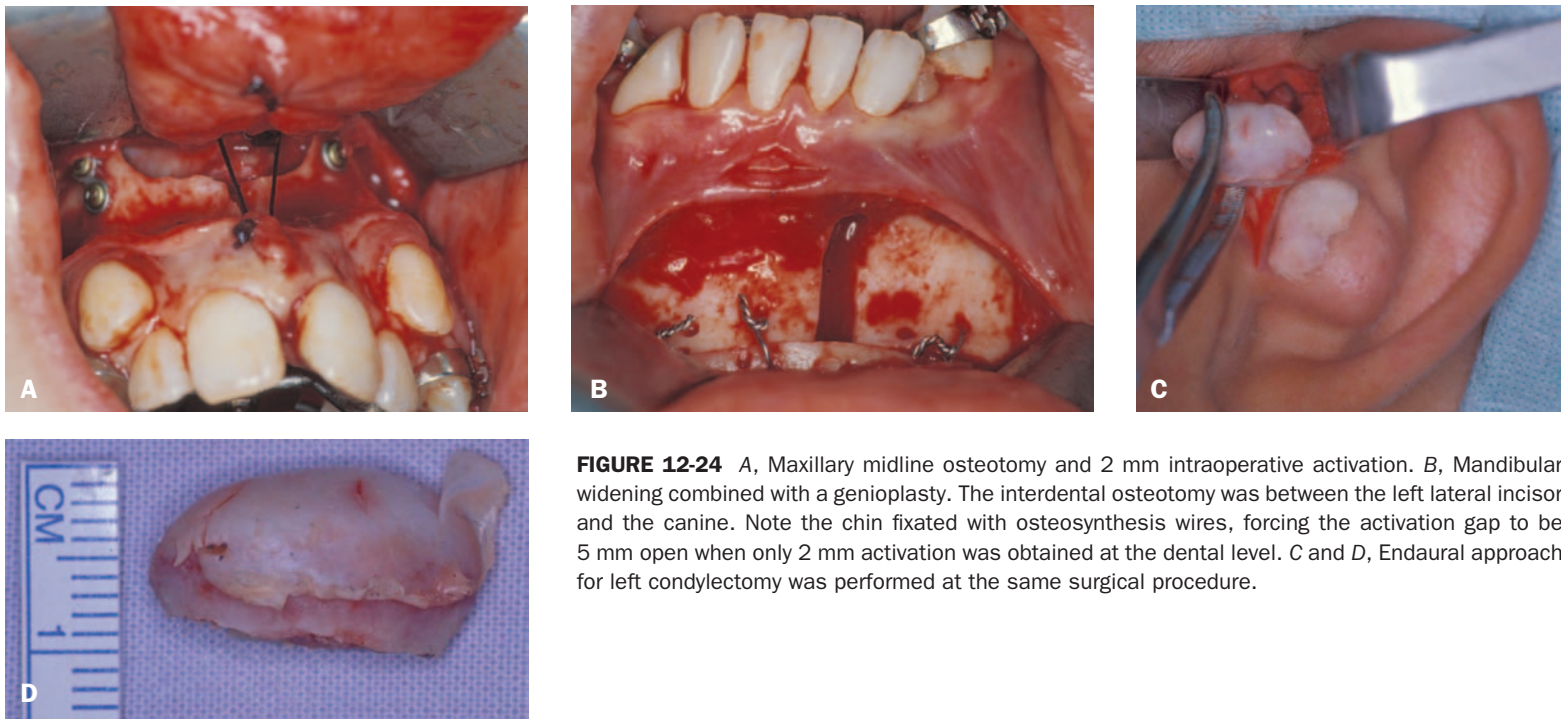


FIGURE 12-24 A, Maxillary midline osteotomy and 2 mm intraoperative activation. B, Mandibular widening combined with a genioplasty. The interdental osteotomy was between the left lateral incisor and the canine. Note the chin fixated with osteosynthesis wires, forcing the activation gap to be 5 mm open when only 2 mm activation was obtained at the dental level. C and D, Endaural approach for left condylectomy was performed at the same surgical procedure.



FIGURE 12-25 A–C, Preoperative dental frontal and lateral views showing the maxillomandibular transverse deficiency with ectopic maxillary canines and impacted left mandibular canine. D–F, After total activation, a plastic tooth was placed in the maxillary arch, and when consolidation was achieved, orthodontic treatment proceeded; the dental tooth was reduced 1 mm on one or both sides once a month depending on the dental midline until the distraction gap was closed. G–I, Postoperative Class I occlusion after 3 years of follow-up.



FIGURE 12-26 A, Maxillary occlusal view showing transverse deficiency, a missing right canine, and an ectopic left canine and a left second premolar. B and C, After complete activation, a plastic tooth is placed to fill the space created into the arch, and when consolidation is achieved, the plastic tooth is reduced 1 mm per side every month and orthodontic treatment is resumed.



FIGURE 12-27 A, Preoperative occlusal view missing the left mandibular canine. B, A uni-arm device was used to widen the mandible between the left lateral incisor and the impacted canine. Note the eruption of the left mandibular canine. C, Three-year follow-up. The teeth were adequately aligned, with no extractions.

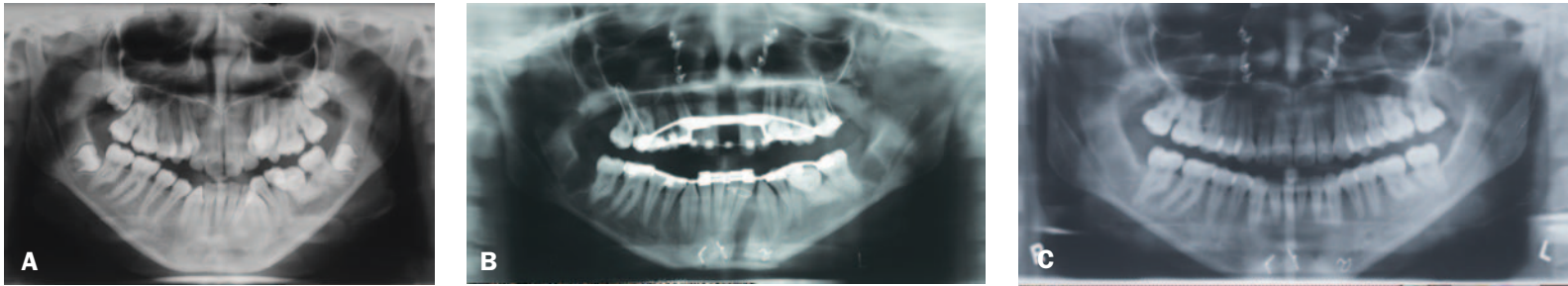


FIGURE 12-28 Panoramic radiographic sequence. A, Preoperatively. B, After the activation period (9.5 mm). C, Three years after surgery.



FIGURE 12-29 A and B, Lateral cephalometric radiograph sequence showing anterior-posterior and vertical changes after completion of desired distraction osteogenesis, maxillary advancement, and genioplasty for vertical reduction. C, Lateral cephalometric radiograph 3 years later.

It is important to maintain the soft tissue pedicle attached to the osteotomized segment, limiting the periosteal elevation to a minimum and avoiding bone resorption.

The reciprocating saw is used for the vertical osteotomy at the preselected distraction site up to the level of the dental apices, the #701 bur is used for the monocortical cut between the roots, and the spatula osteotome is used to complete the osteotomy, with the forefinger protecting the lingual mucosa as previously described (Figure 12-30). The bone-borne device must be fixated parallel to the occlusal plane before the osteotome is used and the osteotomy is completed. Prior to complete bony sectioning, making a horizontal reference line to double check that no changes have occurred in the vertical dimension once the osteotomy is completed is recommended.

To fixate the genioplasty fragment, the 2 mm intraoperative activation is accomplished and a periosteal elevator is placed within the vertical cut at the basal level, forcing the bony segments open while the osteosynthesis wires are tightened up; the segments are kept apart as the wires are twisted during surgery, obtaining more expansion at the

inferior aspect of the distraction site than at the dental level (see Figures 12-24 and 12-31). This allows progressive opening of the distraction gap at the alveolar region during the activation period.

The surgical wounds are closed in the routine layer fashion.

Parasymphyseal Widening

When the vertical cut is designed outside the midline, usually between the canine and the lateral incisor, it is necessary to perform a step osteotomy to avoid facial asymmetries after distraction (see Figure 12-14).

The osteotomy starts as a bicortical cut on the midline at the inferior border of the mandible up to halfway, in the same manner as described for the midsymphyseal widening, and then a bicortical horizontal osteotomy is carried out from the midline to reach the chosen interdental space area, and, finally, the interdental monocortical cut is made with a #701 bur and completed with the spatula osteotome.

The same principles should be followed regarding bone-borne distractor fixation before



FIGURE 12-31 The chin is wired to the alveolar bone fragments once the 2 mm gap of activation is obtained, holding a periosteal elevator within the vertical cut to force the segments to open 5 mm at the basal level while the wires are tightened. This allows postoperative activation.

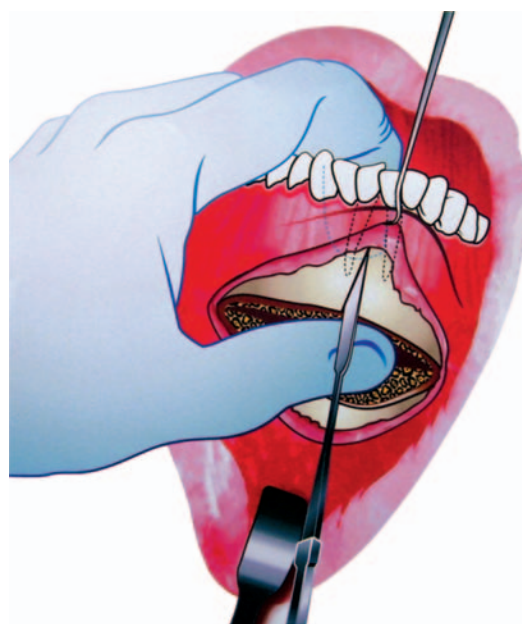
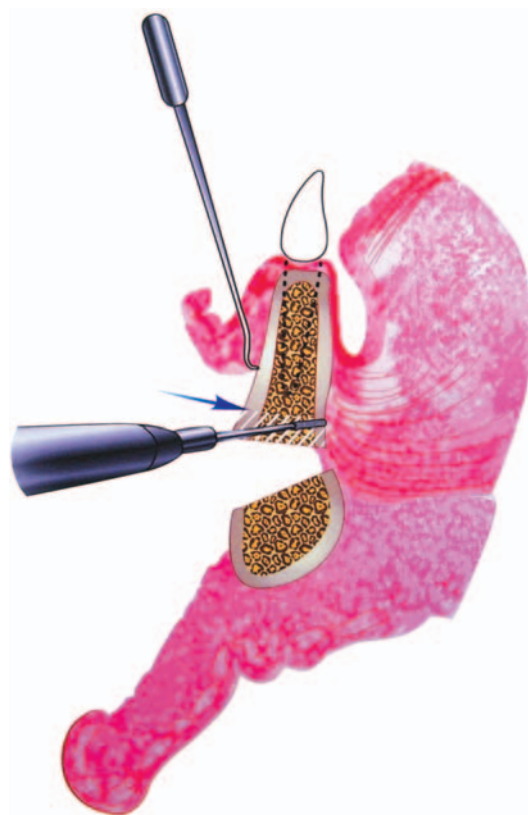


FIGURE 12-30 Combined genioplasty and mandibular widening. A, Genioplasty osteotomy is accomplished, leaving the periosteum attached as much as possible to enhance healing. A reciprocating saw could be used just to begin the interdental osteotomy at the most inferior portion bicortically up to the level of the apices. A skin hook is used to retract and protect the interdental soft tissues, and a #701 bur is used only for the buccal cortex between the roots and at the most inferior portion of the lingual cortex. No attempt is made to use the saw or the bur between the roots of the teeth. B, A spatula osteotome is used to complete the osteotomy, with the forefinger protecting the lingual mucosa. The distractor must be in place before completing the vertical cut.

complete sectioning and distraction vector parallel to the occlusal plane.

Distraction Protocol

After a 7-day latency period, activation starts at a rate of 1 mm once a day until planned distraction is achieved. If the 0.026-inch gauge wire was not placed around teeth on each side of the distraction gap at the time of surgery, the need to place it at this point to prevent teeth from “walking” into the distraction area must be evaluated to avoid compromising tooth vitality (see Figure 12-22).

The soft tissues at the distraction site area should be monitored during the activation period, and if ischemia occurs, activation should be reduced to 0.5 mm once a day or held for 1 to 2 days to avoid compromising the periodontal tissues and distraction healing.

Once the activation period ends, acrylic is placed on the distraction rod for rigidity and the patient is advanced from a liquid to a soft diet. The orthodontist removes the 0.026-inch gauge dental wires that were placed to prevent the teeth from “walking” and places a plastic tooth in the space created to maintain teeth position and new arch width (see Figures 12-3 and 12-26). The patient is seen every 2 weeks to monitor oral hygiene, healing, and device stability.

After an 8- to 10-week consolidation phase,^{26,27} radiographs are taken, and when continuity of the cortex is observed, the distractor is removed and orthodontic movements to close the gap start. The orthodontist removes 1 mm from one or both interproximal surfaces of the plastic tooth every month depending on the planned dental midline position.

If a bone-borne appliance was used, it is removed by taking out the transmucosal screws and cutting the dental anchoring wires under intravenous sedation and local anesthesia.

Conclusions

Distraction osteogenesis offers a new possibility to predictably treat mandibular transverse deficiency; different osteotomy designs allow the clinician to apply the surgical procedures, avoiding anatomic structures and permitting a wider mandibular arch to align and level the anterior teeth inside the alveolar ridge with ideal axial inclinations, in a stable manner, during a short period of time.

Some particular complications encountered in the past can be easily overcome after 20 years' experience with the surgical technique, especially a wide mandibular chin deformity after mandibular widening, treated today by combining it with horizontal genioplasty to isolate the increase of width at the teeth level, maintaining the chin shape invariable. Also, the creation of a posterior crossbite after unraveling the anterior teeth, secondary to the mandibular widening, is avoided by combining maxillomandibular widening; mandibular widening long-term follow-up studies allowed us to predict the amount of expansion in different mandibular sites, from the intercondylar separation to the intercanine.

Nowadays, we can widen the mandible at any age, as many millimeters as needed, allow the eruption of impacted teeth through distracted bone, select an osteotomy site away from dental roots anywhere in the anterior mandibular area, and continue with orthodontics to align and level the teeth into an ideal position, with no teeth morbidity.

The orthodontic and surgical treatment of mandibular widening can be performed with other orthognathic procedures simultaneously to permit three-dimensional mandibular repositioning, also combined with maxillary surgical procedures to obtain ideal functional, stable, esthetic results in a short period of time. Mandibular widening offers a new tool in the treatment armamentarium for dentofacial deformities.

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Speedy Surgical Orthodontic Treatment with Skeletal Anchorage in Adults

Kyu-Rhim Chung, Seong-Hun Kim and Yoon-Ah Kook

Esthetic improvement for adult patients is progressively becoming more significant as an objective of orthodontic treatment. This trend has grown in conjunction with an increase in life span and a decrease in number of children, which enables greater personal expenditure. Adults increasingly desire both better esthetics and a short orthodontic treatment time. In order to meet the new demand, clinicians have recommended improved techniques. The most promising is speedy surgical orthodontic intervention using skeletal anchorage, for cases where growth has ceased and the possibility of growth modification is limited.^{1,2}

Adults, compared with young patients, possess characteristics such as spongy bone reduction, an increase in cortical bone density, a decrease in bone volume, and apical displacement of the marginal bone level, which limit the usefulness of conventional orthodontic treatment.³⁻⁵ As a result, such problems as marginal bone loss, root exposure, root resorption, and prolonged treatment time often occur in cases involving adults (Figure 13-1).⁴⁻⁸ In addition, the characteristics of the anterior alveolar bone have an adverse impact on efforts to remodel bone, particularly in adult bimaxillary protrusion cases that display incompetence in lip repose. The anatomic limits set by the cortical plates of the alveolus at the level of the incisor apices act as orthodontic walls.⁹ Posttreatment results show less remodeling than desired, and severe resorption has occurred when conventional orthodontic treatment was performed alone (Figure 13-2). Therefore, to avoid these complications and meet the patient's demand for short treatment time, surgically assisted orthodontics such as corticotomy should be considered.

Corticotomy as an Alternative to Orthognathic Surgery

Surgical intervention, including orthognathic surgery and corticotomy, can expand the orthodontic treatment boundary and improve

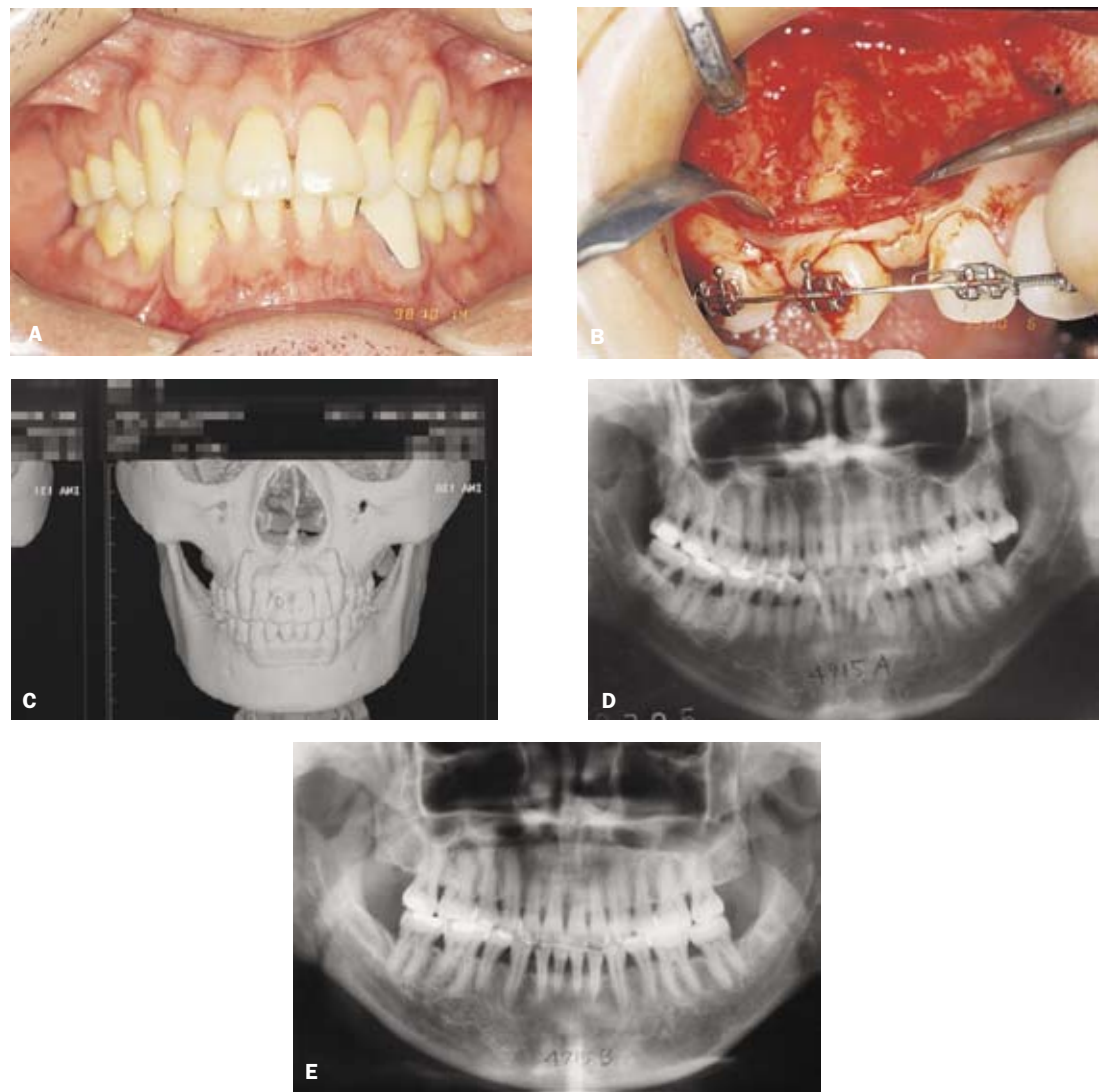


FIGURE 13-1 A, The result of prolonged treatment in an adult: despite extraction of four bicuspids, the crowding problem has relapsed significantly with a loss of a marginal alveolar bone. B, Root exposure occurring during canine retraction: the root of a canine being retracted on an arch wire by conventional methods has been exposed labially (fenestration). This is due to resorption of the labial alveolar bone caused by friction between the root surface and the alveolar bone. C, A three-dimensional computed tomography image of an adult after treatment. The alveolar bone covering the canine root is very thin. This means that a canine bracket with increased positive lingual root torque should be used in buccal canine retraction, especially in adults with less spongy bone. D, Pretreatment panoramic radiograph of a 37-year-old female requiring correction of bimaxillary dental protrusion and alignment. Careful treatment considering the characteristics of adult alveolar bone was administered for 3 years. In the posttreatment panoramic view (E), the loss of marginal bone is clearly shown in the anterior portion.

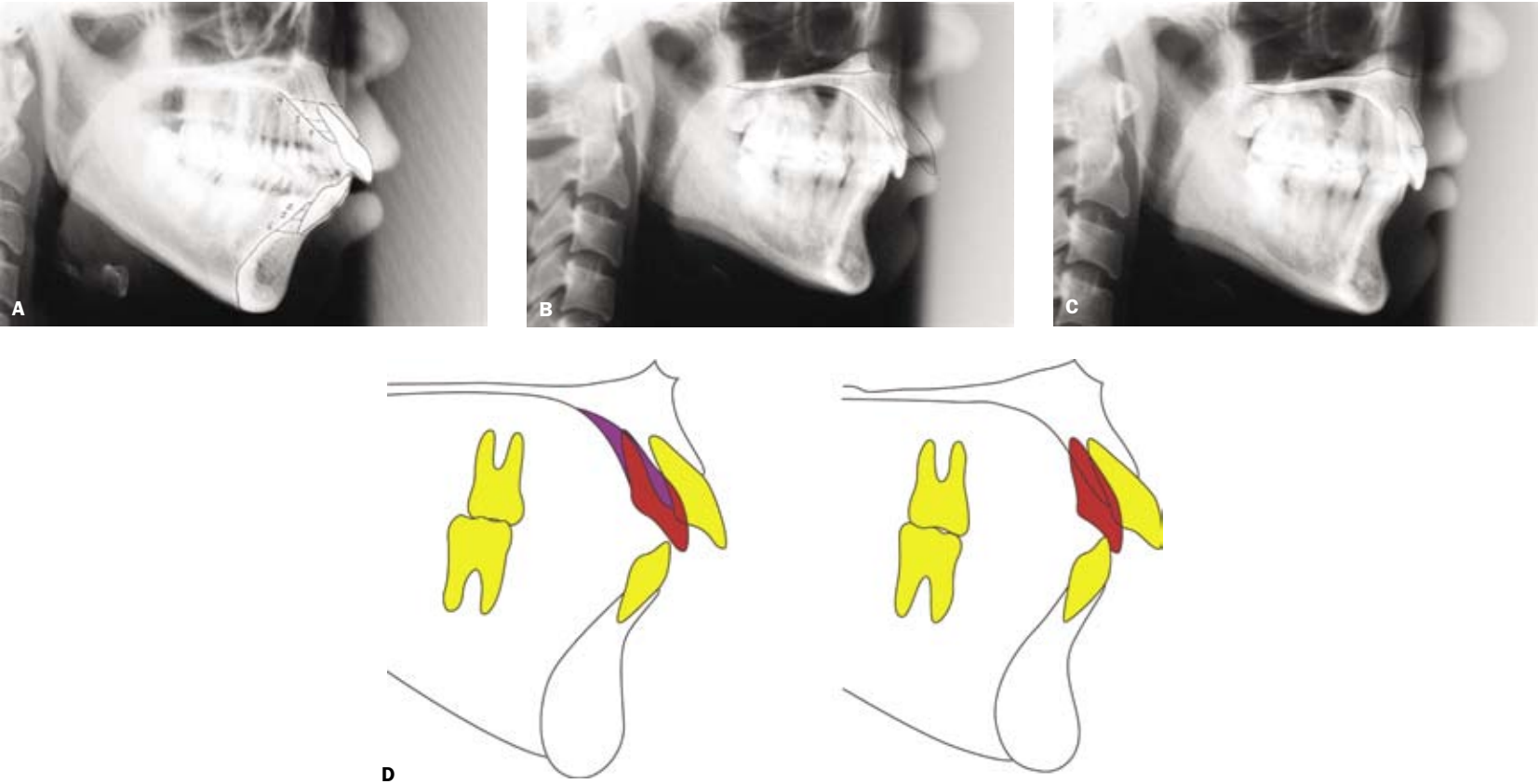


FIGURE 13-2 A, The outline and thickness of the alveolar bone of a 37-year-old female. The limit of lingual movement of the incisors can be predicted by measuring the thickness of anterior alveolar bone on a line parallel to the occlusal plane. The thickness at the midroot level is only 5 mm in the maxilla and 3 mm in the mandible, including 2 mm of cortical bone. B, C, The positional change of the anterior dentition in the anterior protrusion patient is illustrated. A large amount of lingual movement of upper anterior teeth has been achieved (B). When the pretreatment outline of the lingual cortical bone in the upper incisor area is superimposed, it can be seen that bone resorption occurred rather than bone remodeling (C). D, In contrast with growing patients, cortical bone remodeling at the root apex does not occur in most adults. In order to avoid resorption, surgically assisted orthodontics is recommended.

a patient’s appearance in a short time. Orthognathic surgery has been widely done and various kinds of surgical techniques have been developed, but the need of general anesthesia, complications of osteotomy sites, and patient’s financial problems have led the clinicians to develop alternatives.^{10–13}

Therefore, corticotomy presents a more viable alternative solution, in that osteotomies are performed on the cortical layer only and the compact bone is separated (Figure 13-3).^{14–18}

Patients may, for financial or psychological reasons, feel more comfortable with corticotomy than orthognathic surgery, because general anesthesia or special equipment is not necessary.

With corticotomy, a rapid and effective orthodontic treatment reducing ischemic damage on teeth or periodontium is attainable, because only the cortical layer that provides the primary resistance to orthodontic movement is broken off. This maintains the continuity of the medullar bone.^{19,20} It is due to the fact that the collateral

circulation between the osseous and soft tissue, the intraosseous collateral circulation, and the vascular anastomoses between the periodontal, gingival, floor of the nose, and palatal plexuses permit the corticotomy to be performed without jeopardizing the intraosseous or intrapulpal circulation, when the bone cuts are away from the apices of the teeth (Figure 13-4).²¹

Serious side effects do not occur in corticotomy. However, some gingival recession, loss of interdental papillae, or alveolar bone resorption may result, owing to reduced blood flow caused by periosteal elevation or thermal damage during the surgical procedure.²² Corticotomy is often used for rapid palatal expansion in the adult patient and for individual tooth movement including ankylosed teeth.^{23–25}

Biologic and Clinical Foundations of Corticotomy-facilitated Orthodontic Treatment

Even though corticotomy has been applied for more than a hundred years, a lack of effort to apply the procedure to orthodontic treatment has rendered orthodontists or oral surgeons unfamiliar with this technique. The surgical design and its clinical applications for corticotomy-facilitated

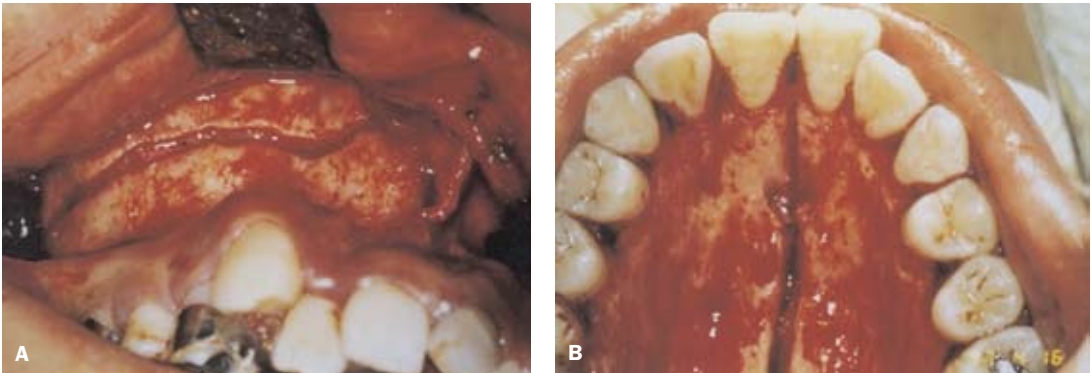


FIGURE 13-3 Corticotomy is performed for reducing the skeletal resistance to orthodontic expansion by surgical removal of the cortical layer at the lateral maxillary buttress (A) or the palate (B).

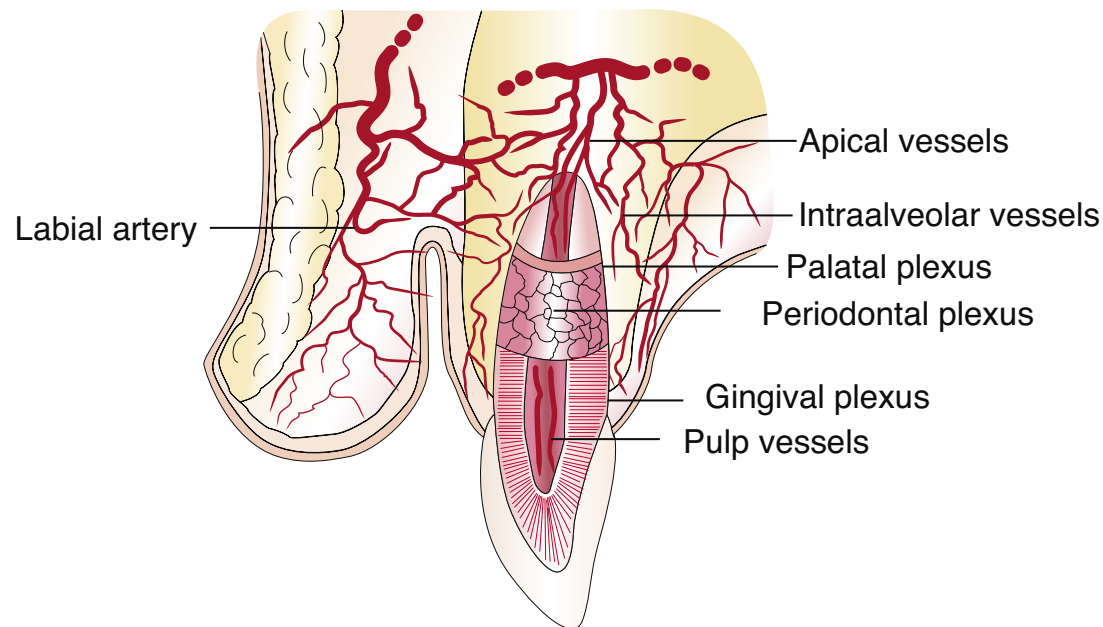


FIGURE 13-4 Schematic illustration of the vascular architecture of the anterior maxillary region. This collateral circulation permits anterior maxillary interdental and subapical osteotomies without jeopardizing the intraosseous or intrapulpal blood supply. Reproduced with permission from Bell WH.¹⁵

orthodontic treatment were first described by Köle, in order to shorten the orthodontic treatment time and eliminate the risk of necrosis of the bone and the dental pulp.¹⁴ However, the removable appliances used in his article had limitations in rendering the orthopedic force necessary for the movement of segments on which corticotomy was performed (Figure 13-5).

Various types of orthopedic force applications to corticotomized segments were studied by many authors.^{26–29} Kawakami and colleagues observed histologic changes at the suture area when the maxillary anterior segment was retracted backward after corticotomy.²⁶ According to their study, changes in the number of cells, the irregularity of functional arrangement of cells and fibers, the amount of bone resorption and apposition, and the width of sutures increased after the corticotomy were seen mostly in the cortical layer, whereas minimal changes were noticeable in spongy bone.²⁶ Yoshikawa suggested that

corticotomy accompanying orthopedic force was efficient for maxillary retraction, based on the fact that the amount of force used in his experiment, equivalent to 1,500 to 1,800 g for human adults, did not damage the soft tissue of the experimental animals.²⁹

Speedy Orthodontics™

Definition

The histologic changes by orthopedic traction forces to a corticotomized segment are called compression osteogenesis (CO).² The basic concepts of CO and distraction osteogenesis (DO) are similar. However, CO differs from DO in that CO requires more extensive removal of cortical bone than does DO. This is because CO is performed by compressing one cut-end closer to the other when the cortical bone is removed, which also induces medullar bone resorption (Figure 13-6: pure CO). The medullar bone

around the anterior teeth can be easily bent by retraction force if the cortical layer between the basal and alveolar bones is removed (Figure 13-7).³⁰ The present authors call it “bending CO.” The cortical bone near the incisive canal resists against bending compression, but it yields to bending compression over time.

Speedy Orthodontics is defined as corticotomy-facilitated orthodontic treatment that combines corticotomy and orthopedic force application. It generates the CO in the corticotomized segment during orthopedic traction.

New Types of Skeletal Anchorage Appliances: C Orthodontic Skeletal Appliance

The success of Speedy Orthodontics depends on the application of orthopedic force after corticotomy. Tooth-borne anchorage always

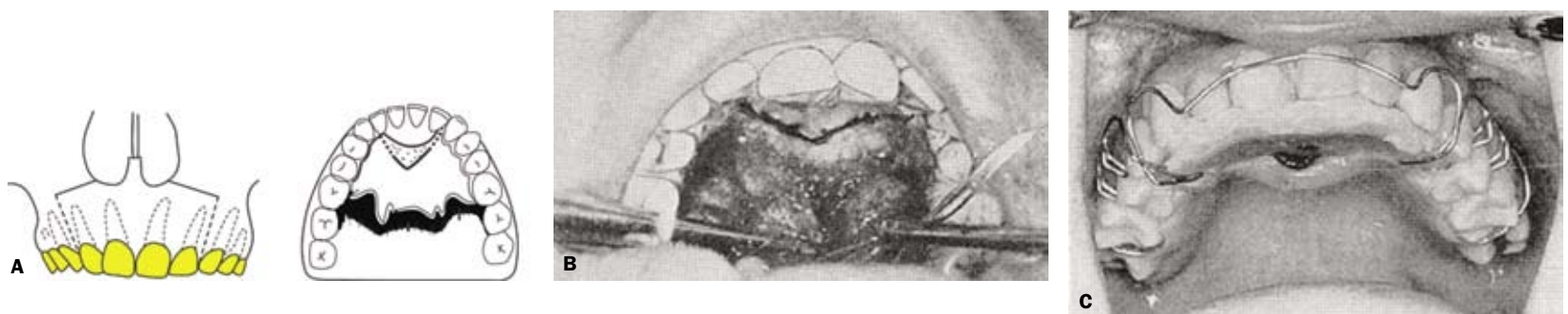


FIGURE 13-5 A, Köle's surgery design for forward movement of the maxillary anterior segment. Corticotomy was performed (as shown in B) and a removable appliance was used for the segmental movement (C). From Köle H. *Surgical Operations on the Alveolar Ridge to Correct Occlusal Abnormalities*. Vol. 12, No 5.

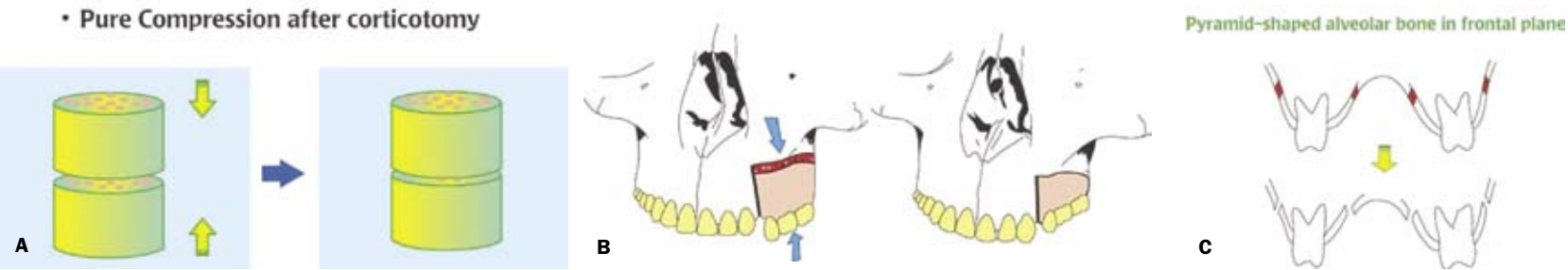


FIGURE 13-6 A, Pure compression osteogenesis (CO). It requires more extensive removal of cortical bone than distraction osteogenesis. CO induces the medullary bone resorption by compressing both cut ends toward each other. B, C, Pure CO can be applied to correct the anterior open bite caused by anteroposterior vertical discrepancy of basal and alveolar bones.

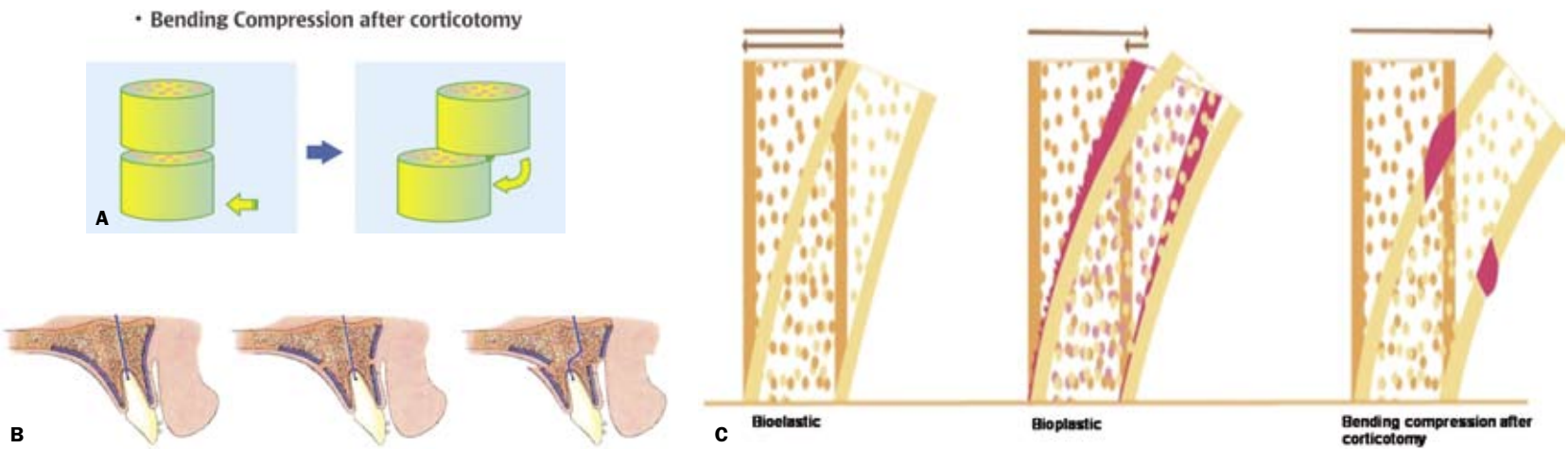


FIGURE 13-7 Schematic illustration of bending compression osteogenesis (A) and the sequence of anterior retraction after corticotomy (B). The medullary bone around anterior teeth can be easily bent by retraction force if the cortical layer between the basal and alveolar bone is removed. C, Different forms of bone deformation. The term “bioelastic” means the property of bone to return to its original dimension when the force applied on the bone is released, whereas the term “bioplastic” implies partial deformation of bone. Once bone is deformed after corticotomy, its recovery to its original dimensions is as impossible as if the greenstick fractured bone were ossified as it was deformed.

receives an equal and opposite force, so it is necessary to apply complicated mechanics or supplementary appliances to control the anchorage (Figure 13-8). On the other hand, extraoral appliances can provide stable anchorage but it depends totally on patient cooperation. Therefore, intraosseous anchorage is preferred to dental or extraoral anchorage.

Speedy Orthodontics using intraosseous anchorages are among the alternative orthodontic treatments that can achieve a result equivalent

to that of an osteotomy. Intraosseous anchorage enables clinicians to move the corticotomy segment rapidly without any extraoral appliance.^{31–38} Moreover, clinicians can expect increased levels of patient cooperation and faith, because they are able to solve the patient’s chief complaints. Their treatment can be more rapidly completed, providing a more natural and cosmetic appearance than the conventional orthodontic treatment.

However, skeletal anchorage appliances for Speedy Orthodontics should bear not only

orthodontic force but also orthopedic force. If they are designed to accommodate arch wires in the case of anterior retraction, then the number of teeth employed for leveling the arch wires can be reduced, preventing damage to teeth and the periodontium that comes from prolonged wearing of appliances.³⁹ Furthermore, the head design of a skeletal anchorage appliance should be suitable for multidirectional force application.

In order to overcome the limitations of conventional skeletal anchorage and to achieve

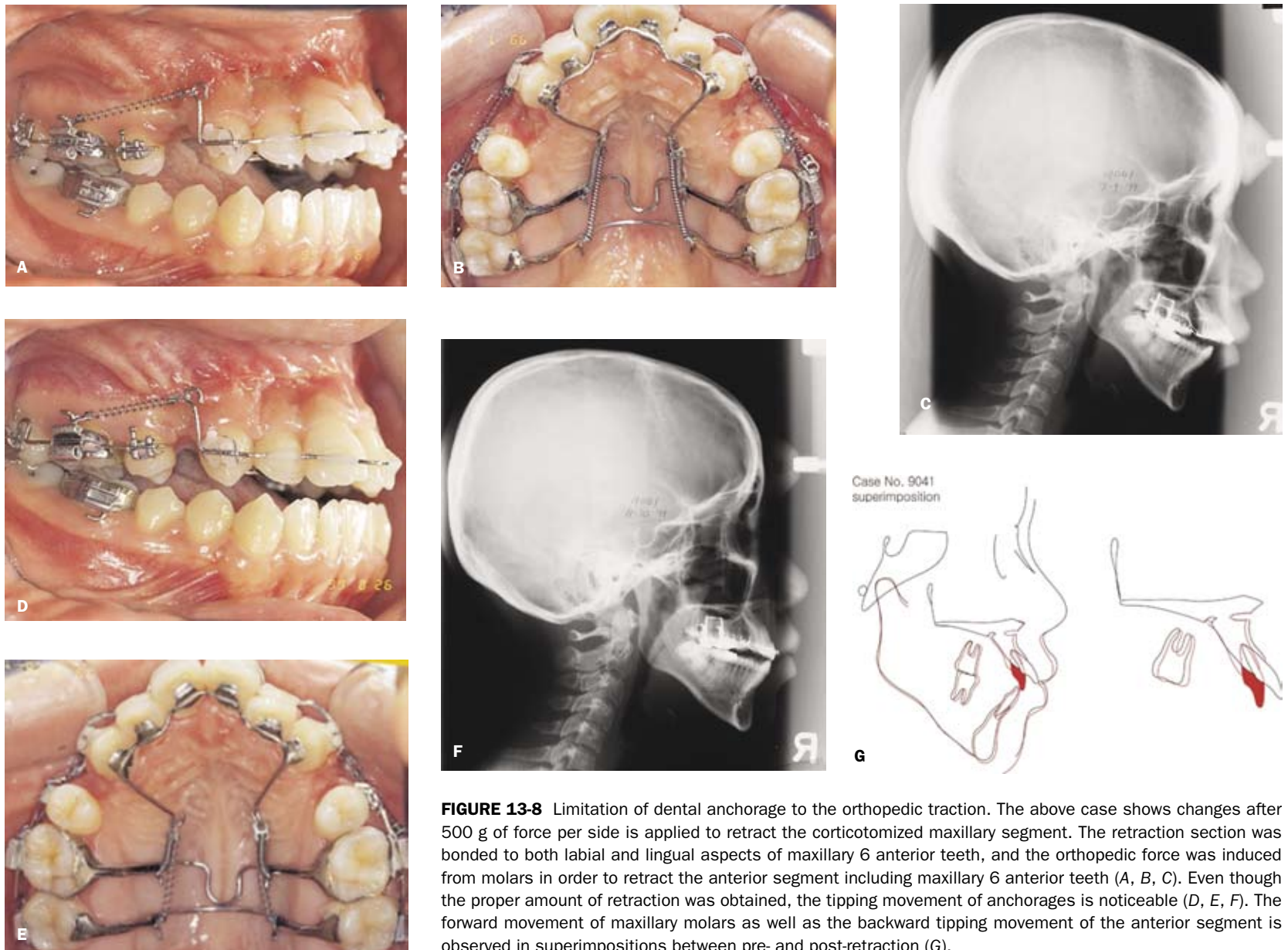


FIGURE 13-8 Limitation of dental anchorage to the orthopedic traction. The above case shows changes after 500 g of force per side is applied to retract the corticotomized maxillary segment. The retraction section was bonded to both labial and lingual aspects of maxillary 6 anterior teeth, and the orthopedic force was induced from molars in order to retract the anterior segment including maxillary 6 anterior teeth (A, B, C). Even though the proper amount of retraction was obtained, the tipping movement of anchorages is noticeable (D, E, F). The forward movement of maxillary molars as well as the backward tipping movement of the anterior segment is observed in superimpositions between pre- and post-retraction (G).

optimal immediate or early skeletal fixation, the author has developed new types of skeletal anchorage appliances, named C-tube, C-palatal plate, and C-implant (Figure 13-9).³⁹⁻⁴⁹ Implementation of an orthodontic tube to a miniplate, named C-tube, would greatly improve the versatility of the rigid anchorage system (see Figure 13-9A).⁴⁰⁻⁴² The small size (1.8 mm in diameter, 8.5mm in length), two-part design, efficiency, and low cost of the C-implant make it

suitable for application in various cases (see Figure 13-9B).^{39,43-46} The surface, except for the upper 2 mm, is sand-blasted, large-grit, and acid-etched (SLA). The C-palatal plate consists of two titanium miniplates joined together in a cross-figure and was developed for a better skeletal anchorage in the palatal area (see Figure 13-9C).^{47,49} The C-orthodontic skeletal appliances can be used as independent orthodontic treatment system in themselves as well as an

auxiliary to the conventional orthodontic mechanics.

Indication

Corticotomy-facilitated orthodontic treatment is indicated for the patient who presents with severe bimaxillary protrusion, with normal depth of the mandibular occlusal plane or maxillary alveolar protrusion with anterior open bite. Skeletal open bite can be closed by decreasing the height of the

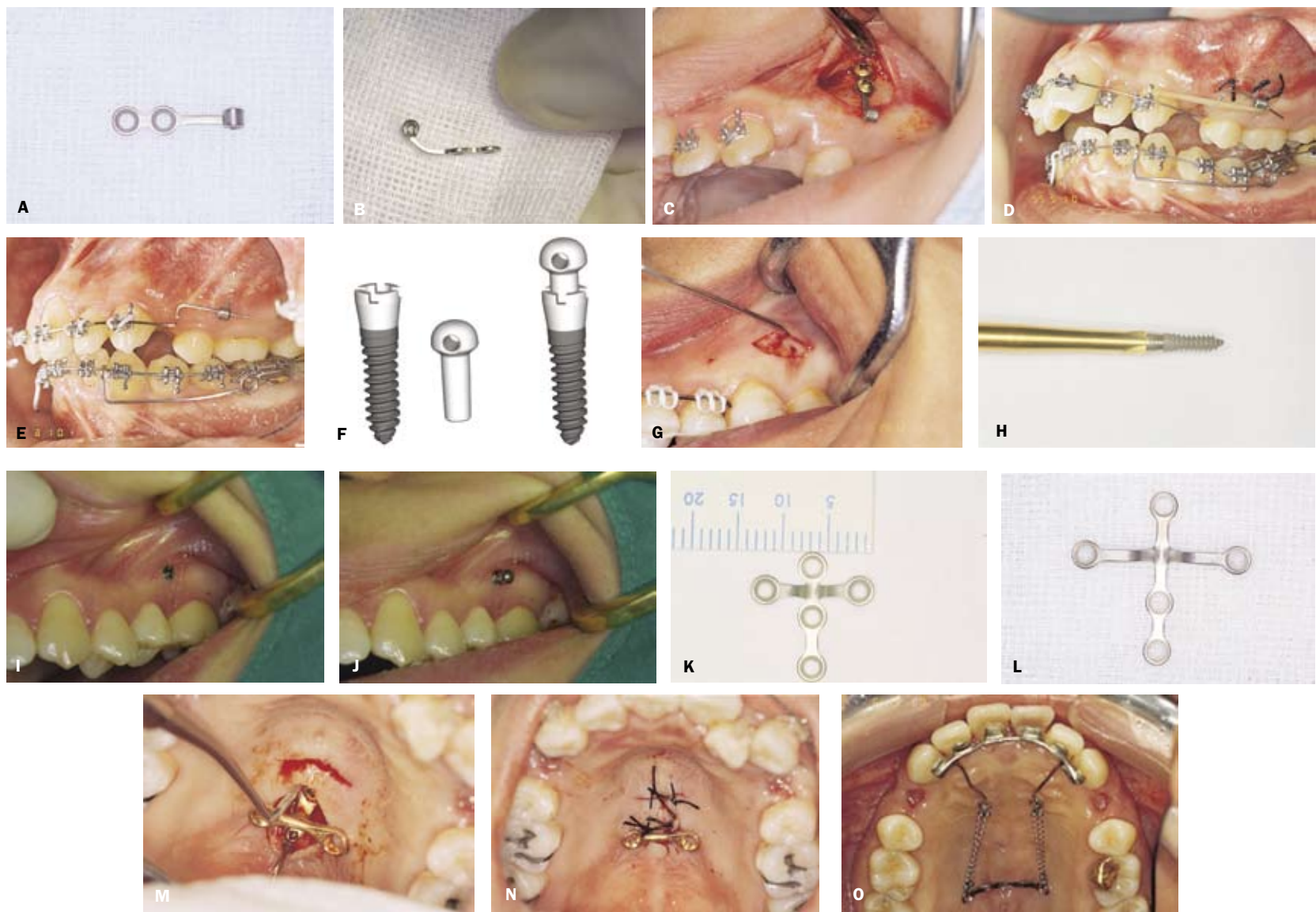


FIGURE 13-9 New types of orthodontic skeletal appliances used for the Speedy Orthodontics treatment. A through E, Implementation of an orthodontic tube to a miniplate, named C-tube, would greatly improve versatility of the rigid anchorage system. In the case of hard and thick cortical bone, make a small hole using a 1.2-mm-diameter bur and fix the C-tube with screws. F through J, The C-implant can be easily implanted between the upper second premolar and first molar. Under local anesthesia, the small size, two-part design, efficiency, and low cost of the C-implant make it possible to apply in various cases. K through O, The C-palatal plate consists of two titanium miniplates joined together in a cross-figure and was developed for a better skeletal anchorage in the palatal area. O, Occlusal view of the C-plate and C-lingual retractor on the palate.

maxillary alveolar bone, because the mandible can spontaneously rotate when the maxillary alveolar bone is compressed (Figure 13-10: Case K.G.P.). Alignment of the mandibular teeth followed by corticotomy-facilitated maxillary segmental retraction is recommended for treatment of Class II Division 1 malocclusion, especially with a severely protruded maxilla. Intraosseous anchorages are sometimes recommended for intrusion of mandibular anterior teeth.

Speedy Orthodontics for Upper Anterior Retraction

Vector Control for Anterior Retraction

Tooth movement in en masse retraction differs, depending on the point of force application in relation to the center of resistance. If retraction force is applied on the center of resistance, then translation occurs. A three-dimensional finite-element model has been constructed to

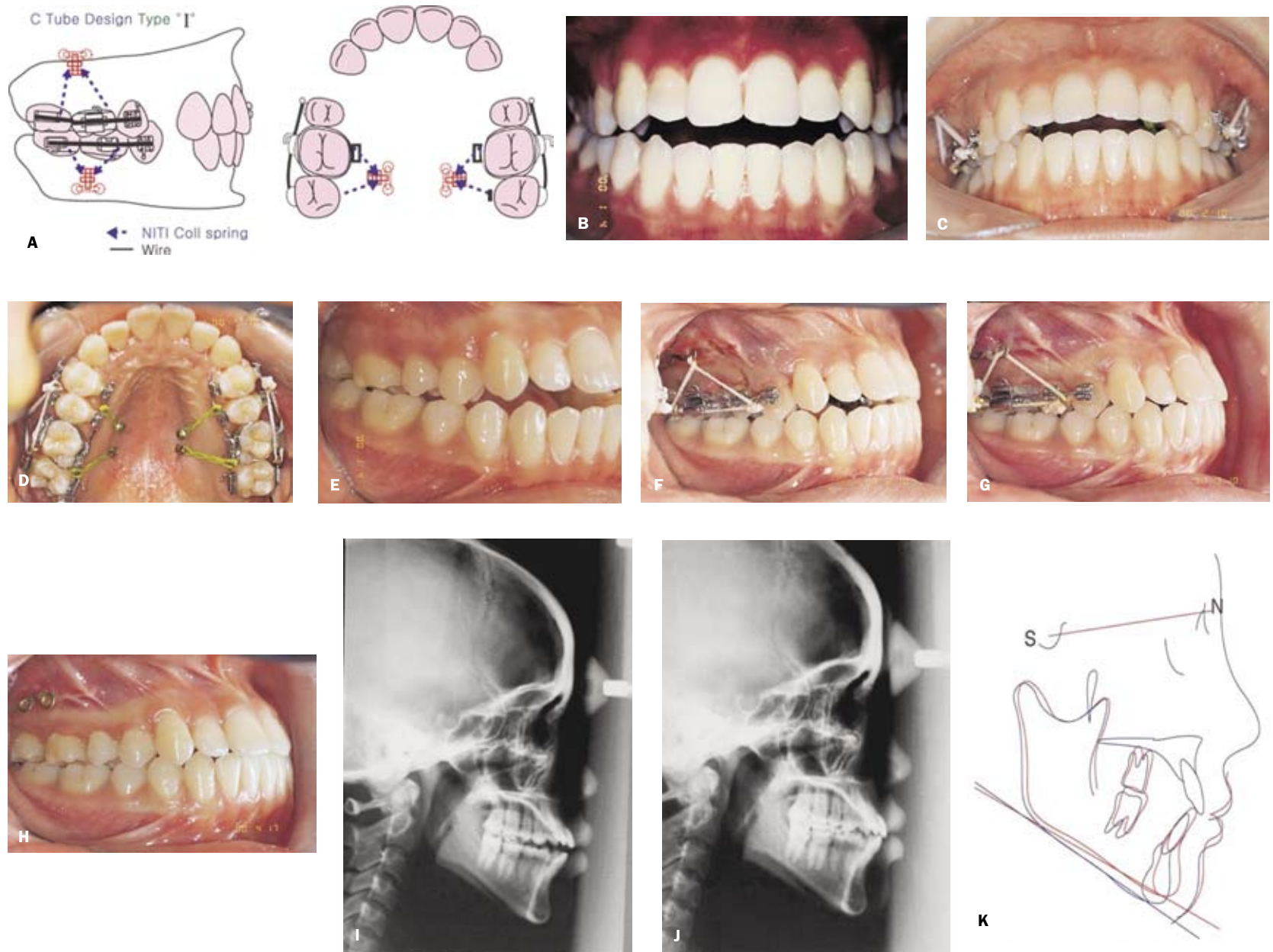


FIGURE 13-10 Case K.G.P. The miniplate and miniscrews were used as intraosseous anchorages for corticotomy-facilitated anterior open-bite correction. The active treatment duration was 3 months. Shown are a schematic illustration of clinical application of intraosseous anchorages (A), occlusion (B), and the intraoral views that show the vertical orthopedic traction of posterior teeth (a force of 400 to 450 g per side) using skeletal anchorage following intrusion corticotomies (C, D). E through H, Speedy orthopedic intrusion of posterior teeth occurred progressively for 3 months. I, J, Lateral cephalograms of pre- and posttreatment. K, Superimposition of pre- and posttreatment shows that counterclockwise rotation of the mandible, normal overjet and overbite, and intrusion of upper posterior teeth were achieved in a short time period.

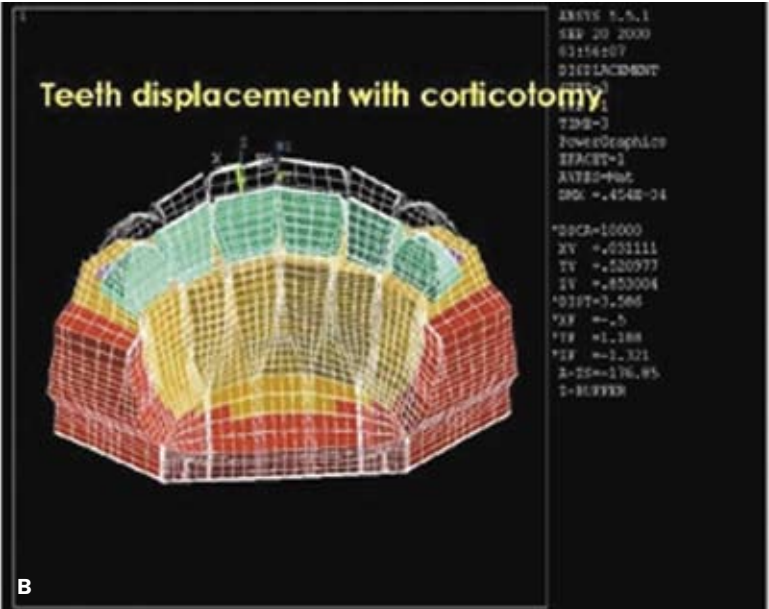
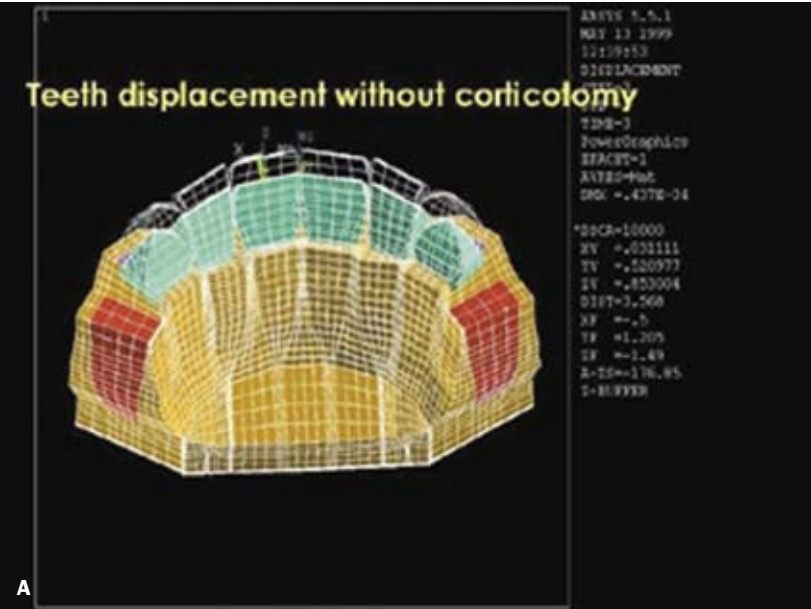
identify the center of resistance (CR) of 6 anterior teeth as a single unit (Figures 13-11A and 13-11B). The CR was found to be 44.32% apical to the cervical area vertically, and 46.38% apical, when corticotomy 5 mm below the root apex of 6 anterior teeth and on the lingual and labial sides of the first premolars was done.⁴⁸ The vertical position of the CR may not change with a difference in force of traction. The author has developed and is using C-lingual retractors for en masse translation of 6 anterior teeth based on these results (Figures 13-11C and 13-11D).

The C-lingual retractor, which is made of a 0.032 inch stainless steel spring wire soldered to mesh brackets, is an alternative method for obtaining a direct controlled retraction force on the maxillary anterior teeth, and for moving the anterior segment as a block.⁵⁰⁻⁵⁵ Because no friction is introduced, precise calibration and accurate tooth movements are possible.

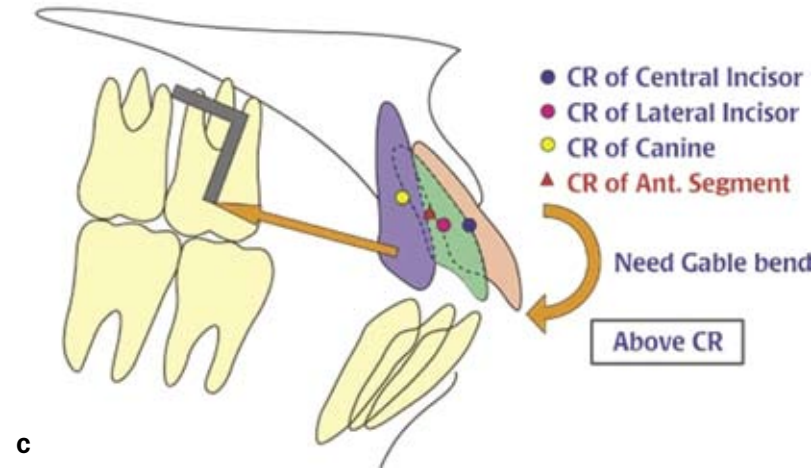
Surgical Technique

Important Factors for Ideal Perisegmental Corticotomy

- The simple design of perisegmental corticotomy helps clinicians achieve the treatment goal while minimizing damage to the periodontium.
- The cut should be wide enough to prevent the rapid reunion of the cut planes on the cortical layer, which makes the segmental movement difficult. If the cutting width is wide enough, segmental movement can be completed before reunion of cut planes on the cortical layer occurs. The cortical cut must be away from the root apices to prevent



Labial Retraction Force Direction



Lingual Retraction Force Direction

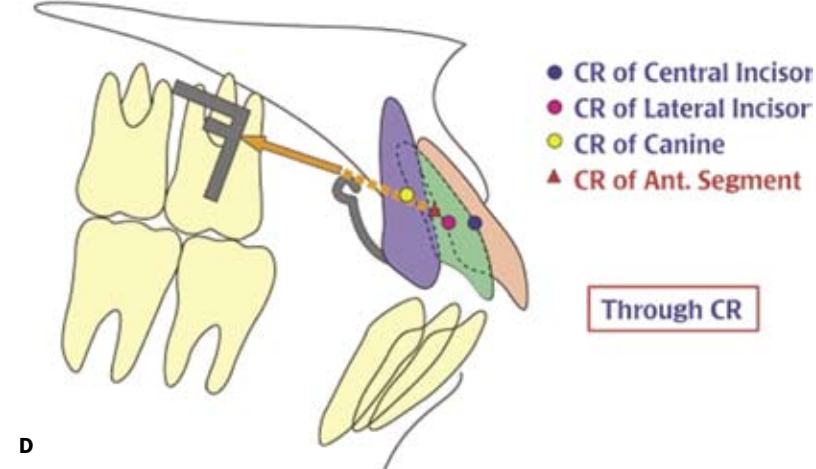


FIGURE 13-11 The CR was found to be 44.32% apical to the cervical area vertically (A) and 46.38% apical, when corticotomy 5 mm below the root apex of 6 anterior teeth and on lingual and labial sides of the first premolars was done (B). The C-lingual retractor consolidates anterior teeth with stiff wires, and the resultant forces are applied directly to the C-lingual retractor, compared with the labial retraction force direction (C, D).

complications such as ankylosis or dislocation of teeth due to pulp damage (Figure 13-12).

- An interval of 2 weeks is optimal between the labial and lingual corticotomies. The completely healed soft tissue on one side can supply enough blood flow for the other side and will burden neither the operator nor the patient.
- Intraosseous anchorages (especially C-orthodontic skeletal appliances) should be applied rather than dental anchorages that require additional time and effort to correct.
- A fixed appliance on every tooth is desirable in order to compensate the canine axis, and early application of heavier arch wires producing less friction is required. The 0.016×0.022 inch or 0.017×0.022 inch stainless steel wires, with which free sliding is

possible, are preferred for the 0.022 slots. The stepped wire or same-sized nickel-titanium wire can be used when the stainless steel wire is not applicable because of difference between levels of anterior teeth and posterior teeth.

Presurgical Approach

1. The surgical work-up, such as mounted models, full-mouth periapical radiographic views, lateral cephalogram, panoramic radiographs, and extraoral and intraoral photographs, are prepared for deciding the surgery type, location and width of bony cut, and the type and number of anchorage with a surgeon. Among these work-ups, the panoramic radiograph can provide very helpful information for this kind of evaluation.
2. The patient is informed of the proposed surgical procedure, and detailed advantages and disadvantages of the procedure. It must be recorded on charts that the care for temporomandibular disorder is going to be excluded from treatment goals if a patient is motivated only by the cosmetic result of rapid orthodontic treatment.
3. Plaster model surgery and cephalometric simulation should be done to predict the path of planned movement (Figure 13-13). In particular, the model surgery allows one to measure arch width discrepancies, and determine the amount of retraction needed.
4. A full-sized, stainless steel, stabilizing arch wire segment is placed passively to stabilize the maxillary posterior segment.

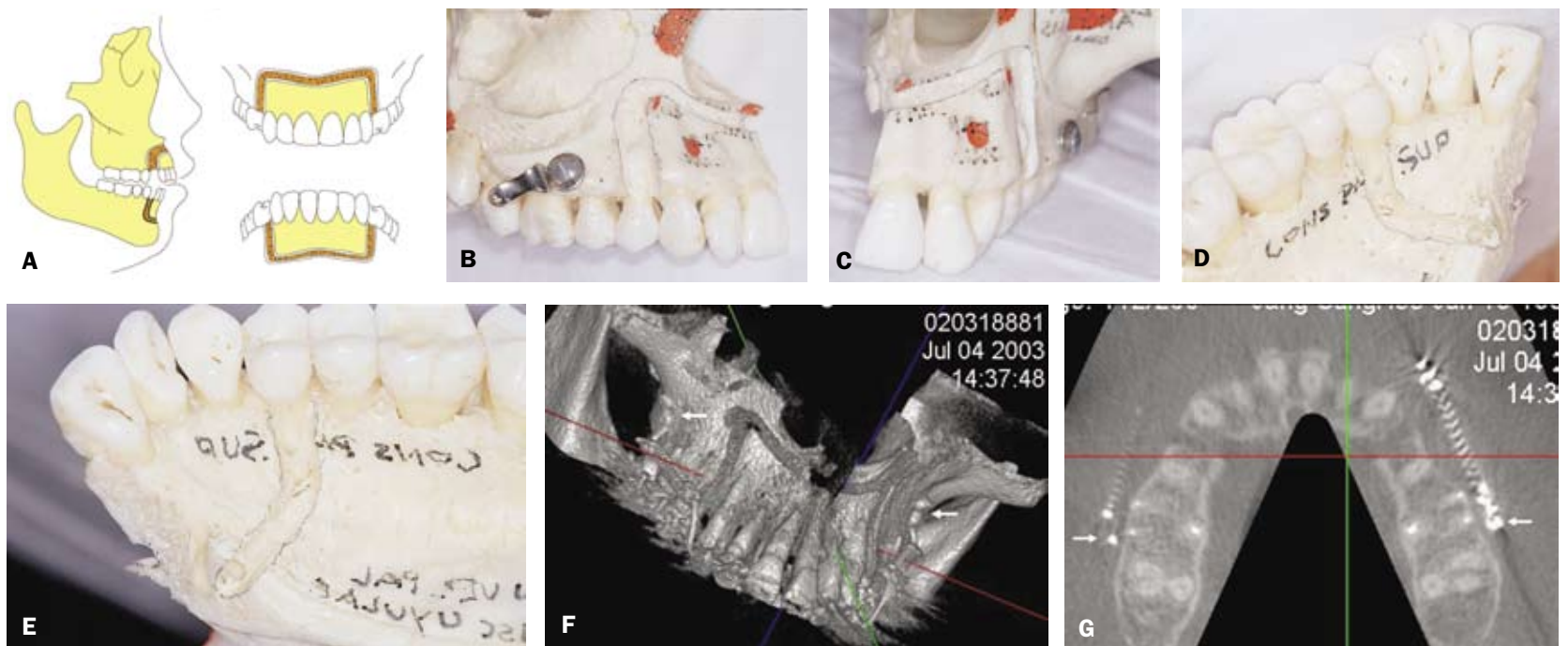


FIGURE 13-12 A, Schematic illustration of the design of perisegmental corticotomy for anterior retraction. The cutting width should be wide enough for the segmental movement to be completed before reunion of cut planes on the cortical layer occurs. B through E, The ideal design of perisegmental corticotomy for anterior segment retraction in the dry skull, right buccal (B), left buccal (C), right palatal (D), and left palatal (E) areas. F, G, Three-dimensional computed tomography views of a 52-year-old female patient (Case S.H.C.) after perisegmental corticotomy; buccal (F) and occlusal (G) views. Note that the anterior segment is retracted by C-tubes (arrow) and a C-plate.



FIGURE 13-13 Model surgery indicates that anterior segment retraction will be interfered with by contacts between the maxillary and mandibular canines owing to a too narrow maxillary intercanine width. The corticotomy should be preceded by labialization of both the upper canines to eliminate interferences.

First Surgery

Maxillary Palatal Corticotomy. The maxillary corticotomy is performed first on the palatal side (Figure 13-14). The mucoperiosteal incision is made along the palatal mucosa and the bone is exposed (see Figure 13-14A). The incisive nerve and artery should be spared. They can be drawn out a little to facilitate the corticotomy (see Figure 13-14B). After the mucoperiosteum has been undermined, a vertical bone cut is made across both first premolar sites with the no. 5 round bur mounted on an angle hand piece, similar to that used in anterior segmental surgery (see Figures 13-14C through 13-14E). The horizontal corticotomy is made 2 cm below the apices of the upper

anterior teeth. This cut is also made with round burs (see Figure 13-14F). The guide for the horizontal cut is the upper first premolar. The spongiosa of the bone serves here as a nutritive pedicle. The palatal incision is then sutured with 4-0 vicryl and covered with a previously fabricated protective acrylic plate to prevent palatal mucosa from being opened by the tongue.

The C-lingual retractor should be bonded to teeth after stitch-out in order to provide an adjustment period for the tongue.

Second Surgery

Maxillary Buccal Corticotomy. After 2 weeks of the first surgery, the second surgery is to be

performed with the extraction of the first premolars (Figure 13-15). The completed soft tissue healing on one side can supply enough blood flow for the other side, and will burden neither the operator nor the patient.

The buccal mucosa is infiltrated with lidocaine and epinephrine from the second premolar to the other second premolar. An incision is made approximately 5 mm below the mucogingival junction and on the dental aspect of the vestibule. The mucosa is raised from the lip, and sharp dissection is continued until the maxilla is reached. At this point, the periosteum is incised and final exposure is obtained by mucoperiosteal elevation. The buccal corticotomy involves a vertical bony cut, beginning at the extraction site

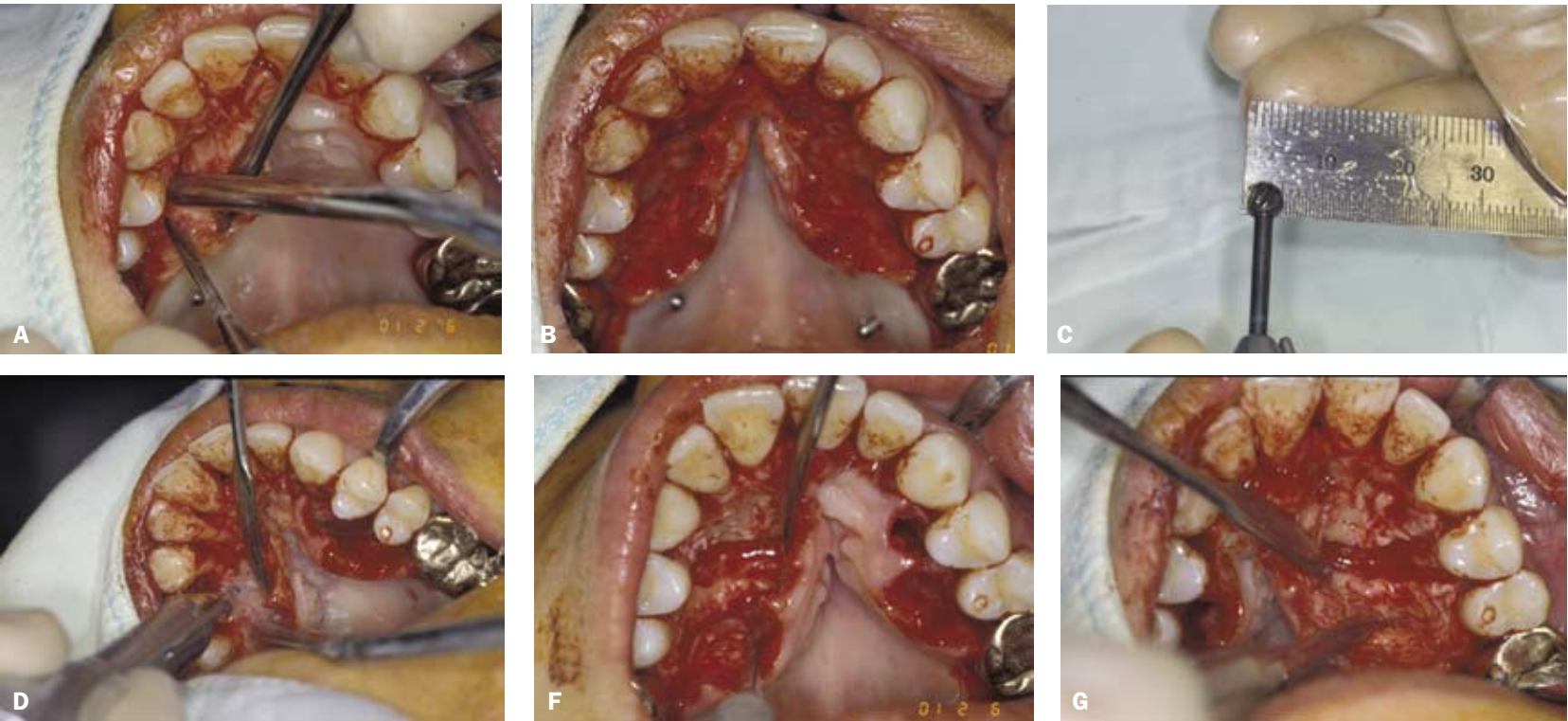


FIGURE 13-14 A through F, Perisegmental palatal corticotomy for anterior retraction. Note that the incisive nerve and artery should be spared. They can be drawn out a little to facilitate the corticotomy.

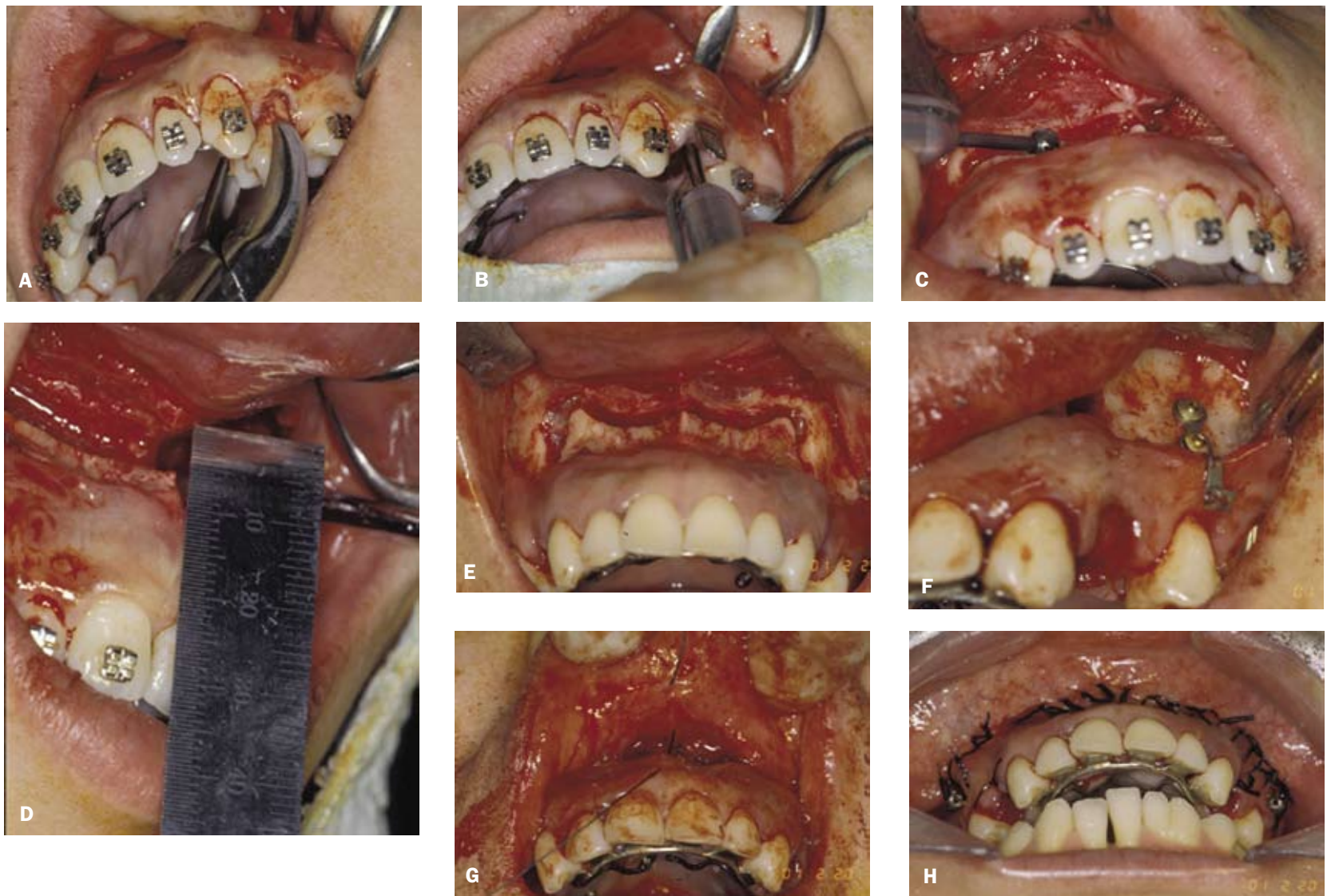


FIGURE 13-15 Perisegmental buccal corticotomy is performed 2 weeks from the first surgery. A connecting vertical bone cut begins 2 to 3 mm above the interdental alveolar margin on the first premolar, and extends through the interdental bone to 2 mm above the apices (A, B). Note that the connecting horizontal cut begins with a no. 5 round bur at the level of a Le Fort I osteotomy (at least 5 mm above the root apices) (C, D). Buccal corticotomy is completed (E). The C-tube and C-plate are placed during the buccal corticotomy (F), and the C-lingual retractor should be bonded to the upper anterior dentition before second surgery for immediate retraction of the anterior segment. Layered suture technique using resorbable silk for the inner layer and nonresorbable silk for the outer layer is performed (G, H).

and extending parallel to the long axis of the canine (see Figures 13-15A and 13-15B). The cant of this vertical bone cut should coincide with the desired direction of retraction of the anterior segment.

A connecting horizontal bony cut is then made with a round bur at the level of a Le Fort I osteotomy (at least 5 mm above the root apices) (see Figures 13-15C and 13-15D). The depth of

the bony cut should be limited to cortical bone, as identified by bleeding in the osteotomy site. The interlinking cut line on the vertical bone should be a smooth curve without any sharp corners (see Figure 13-15E). The C-tube and C-palatal plate are implanted during the second surgery (see Figure 13-15F). Layered suture technique, using resorbable silk for the inner layer and nonresorbable silk for the outer layer, is

preferred (see Figures 13-15G and 13-15H). Scar formation can be minimized by careful tension-free suturing of the outer layer. The rubber drain may be inserted case by case. Analgesics, antibiotics, and cold packs are prescribed as usual for extraction cases.

It is critical to begin the anterior retraction immediately after completion of the surgical procedure, before bony healing occurs.

Case H.S.N.

The patient was a 36-year-old Asian female whose chief complaint was self-consciousness over her poor appearance, caused by protruded front teeth and inability to close her lips without strain. She was diagnosed as the Angle Class II malocclusion,

with deviated midlines and moderate discrepancy between the CR and CO from the clinical and radiographic examination (Figures 13-16A through 13-16G). The treatment strategy was, therefore, to extract all the first premolars to correct the convex profile, perform Speedy

Orthodontics with the upper C-lingual retractor for anterior retraction, and use a miniscrew and C-palatal plate for anchorage re-inforcement. The diagram of the C-lingual retractor combined with Speedy Orthodontics approach is shown in Figure 13-16H.

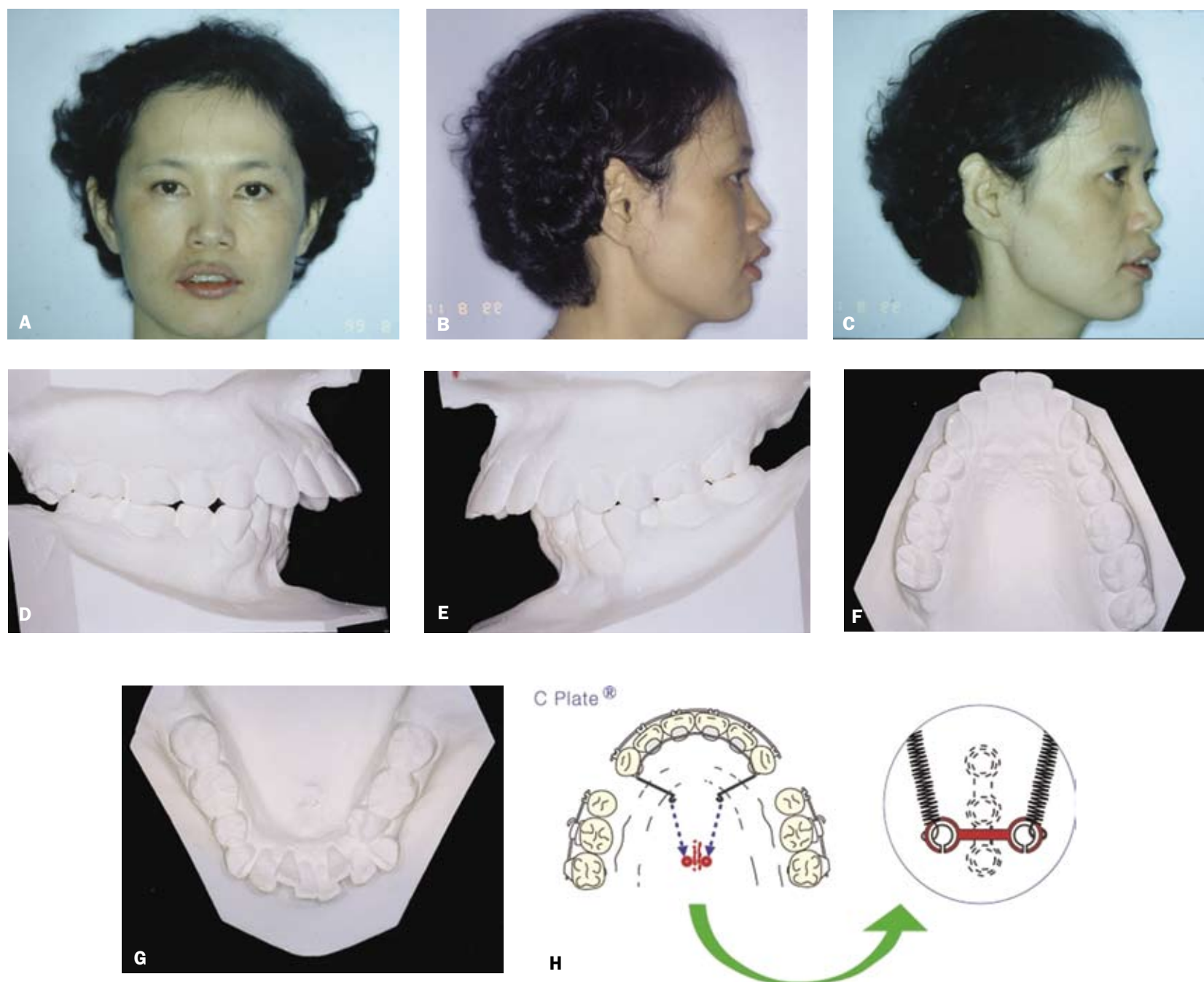


FIGURE 13-16 Case H.S.N.'s pretreatment facial photographs (A, B, C) and study models (D through G). The C-palatal plate and miniscrews were used as intraosseous anchorages for anterior segment retraction (H).

At the cessation of the 4-month C-lingual retractor procedure, the upper anterior retraction was completed (Figures 13-17A through 13-17F, 13-17J, and 13-17K) and routine orthodontic mechanics were continued to finish treatment (Figures 13-17G through 13-17I, and 13-17L). The fixed appliances were all removed after 2 months of conventional orthodontic treatment

(Figures 13-18A through 13-18G). The alignment of the lower anterior teeth could not be completed because of patient rejection. The treatment result was quite acceptable and the patient was pleased with the final treatment result, despite the small remaining extraction space. The total treatment period was 6 months. The retention was provided by upper and lower fixed retainers. Lateral

cephalograms and panoramic radiographs showed that the anterior retraction was completed in 4 months after perisegmental corticotomy, without remarkable root resorption of upper anterior teeth (Figures 13-18H through 13-18N). Superimposition of cephalometric tracings pre- and post-treatment showed that bending CO had occurred during anterior retraction (Figure 13-18O).

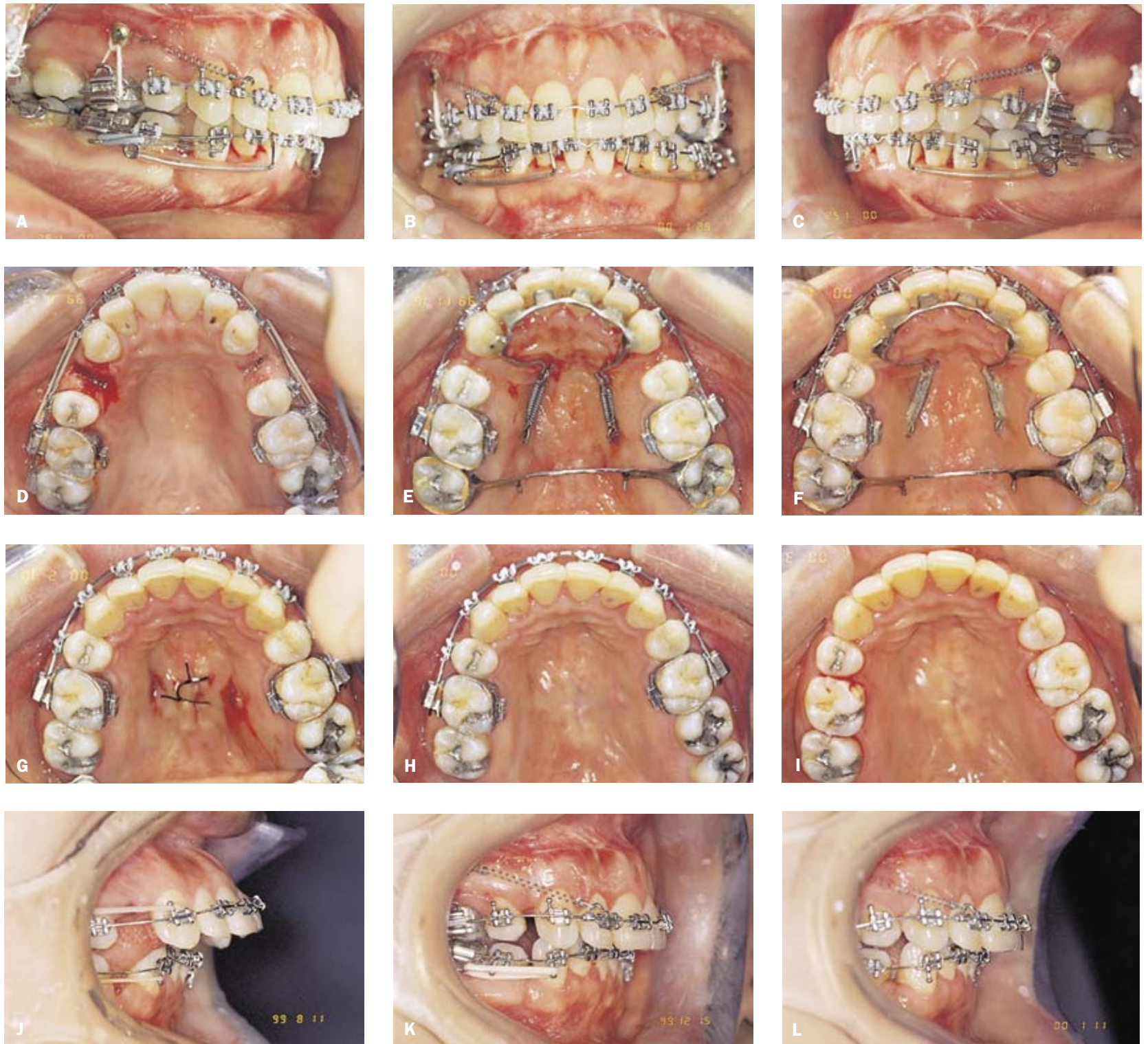
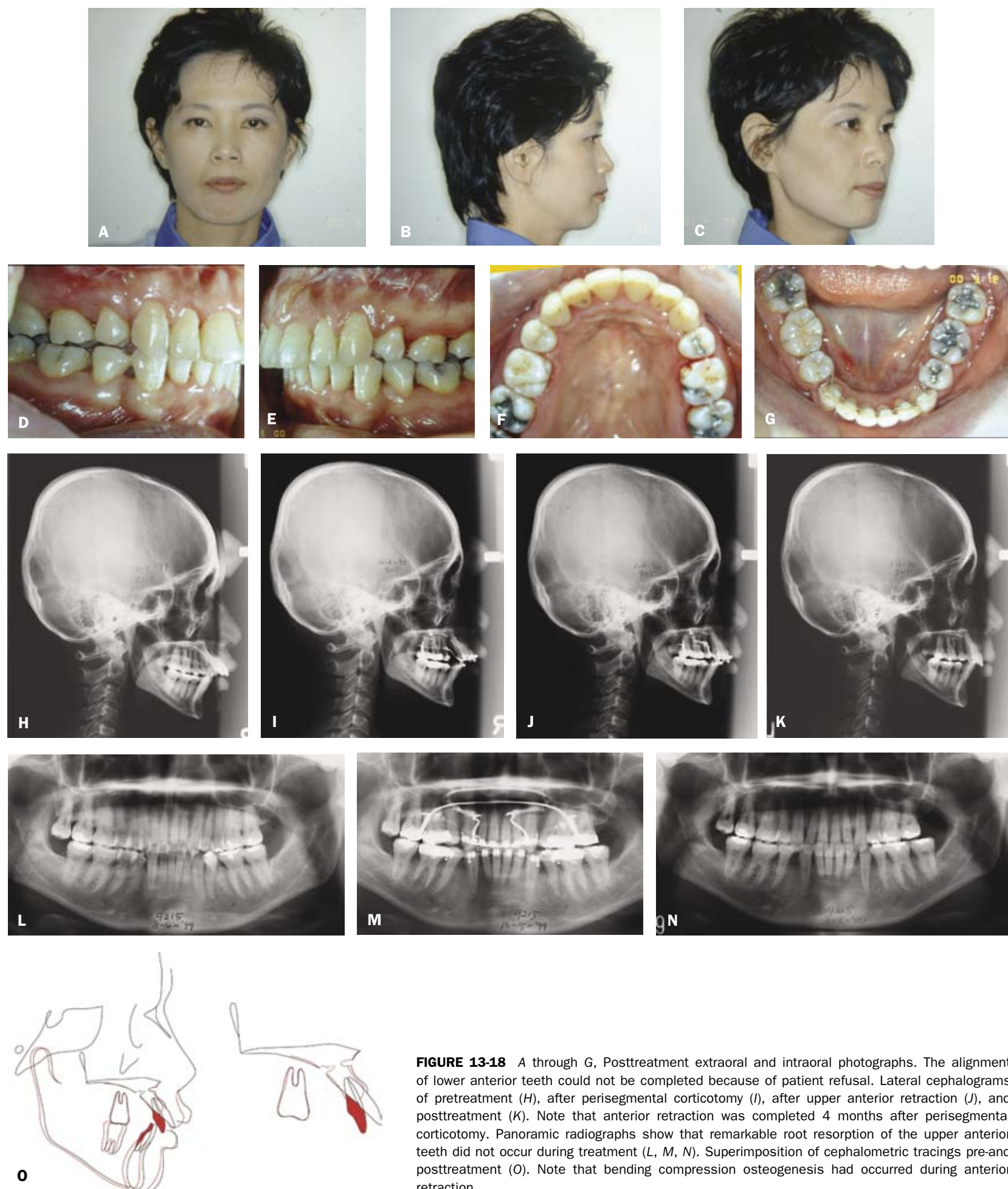


FIGURE 13-17 A, B, C, Completion of upper anterior retraction after 4 months from perisegmental corticotomy: right (A), frontal (B), left sides (C). D through I, Progressive occlusal views from initial leveling to posttreatment. The total treatment period was 7 months: Alignment and leveling was initiated after upper first premolars were removed (D); One month from upper perisegmental corticotomy (E); Upper anterior retraction was completed after 4 months from corticotomy (F); The C-plate was removed during finishing (G) and the palatal soft tissue was healed completely (H); Debonded occlusal view (I). J, K, L, Changes of the overjet during treatment.



Case H.G.O.

A 38-year-old Asian female presented with the chief complaint of lip protrusion, caused by protruded maxillary anterior teeth, and eagerness for an attractive smile (Figures 13-19A through 13-19F). The Angle Class II malocclusion, upper and lower anterior protrusion, and everted lip were clinically discovered.

The treatment plan consisted of extracting both upper first premolars and retracting the upper 6 anterior teeth with Speedy Orthodontics,

using the C-orthodontic skeletal appliances (Figure 13-20). Upper anterior retraction was completed in 5 months after perisegmental corticotomy (Figures 13-21A through 13-21H), and it took 11 months to treat this patient (Figures 13-21I through 13-21P). There was a decrease in lip fullness as the upper anterior teeth were retracted, which contributed to a decrease in facial convexity (Figures 13-22A through 13-22F). We used tip-back mechanics and uprighting sectional arch wires on the lower dentition to correct

the lower incisor axial inclination and intrude successfully during 6 months of conventional orthodontic treatment. Lateral cephalograms and panoramic radiographs showed that the anterior retraction was completed 5 months after perisegmental corticotomy without remarkable root resorption of the upper anterior teeth (Figures 13-22G through 13-22L). Superimposition of cephalometric tracings pre-and posttreatment also showed that bending CO had occurred during anterior retraction (Figure 13-22M).



FIGURE 13-19 Case H.G.O.'s pretreatment facial (A, B, C) and intraoral (D, E) photos. The patient was a 38-year-old Asian female whose chief complaint was her poor appearance caused by protruded maxillary anterior teeth. The Angle Class II malocclusion, upper and lower anterior protrusions, and everted lip were clinically discovered.

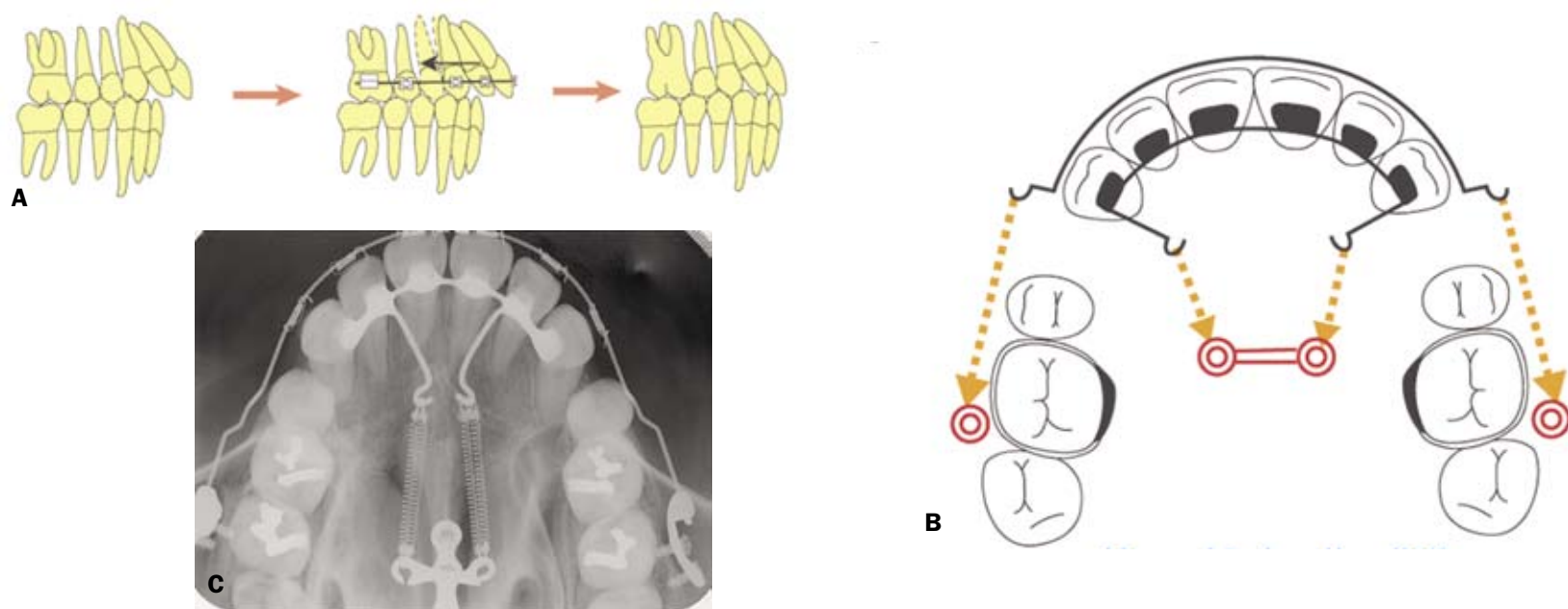


FIGURE 13-20 Schematic illustrations of anterior segment retraction mechanics (A, B) and maxillary occlusal x-ray view (C). Speedy Orthodontics using C-orthodontic skeletal appliances was planned to treat this patient.

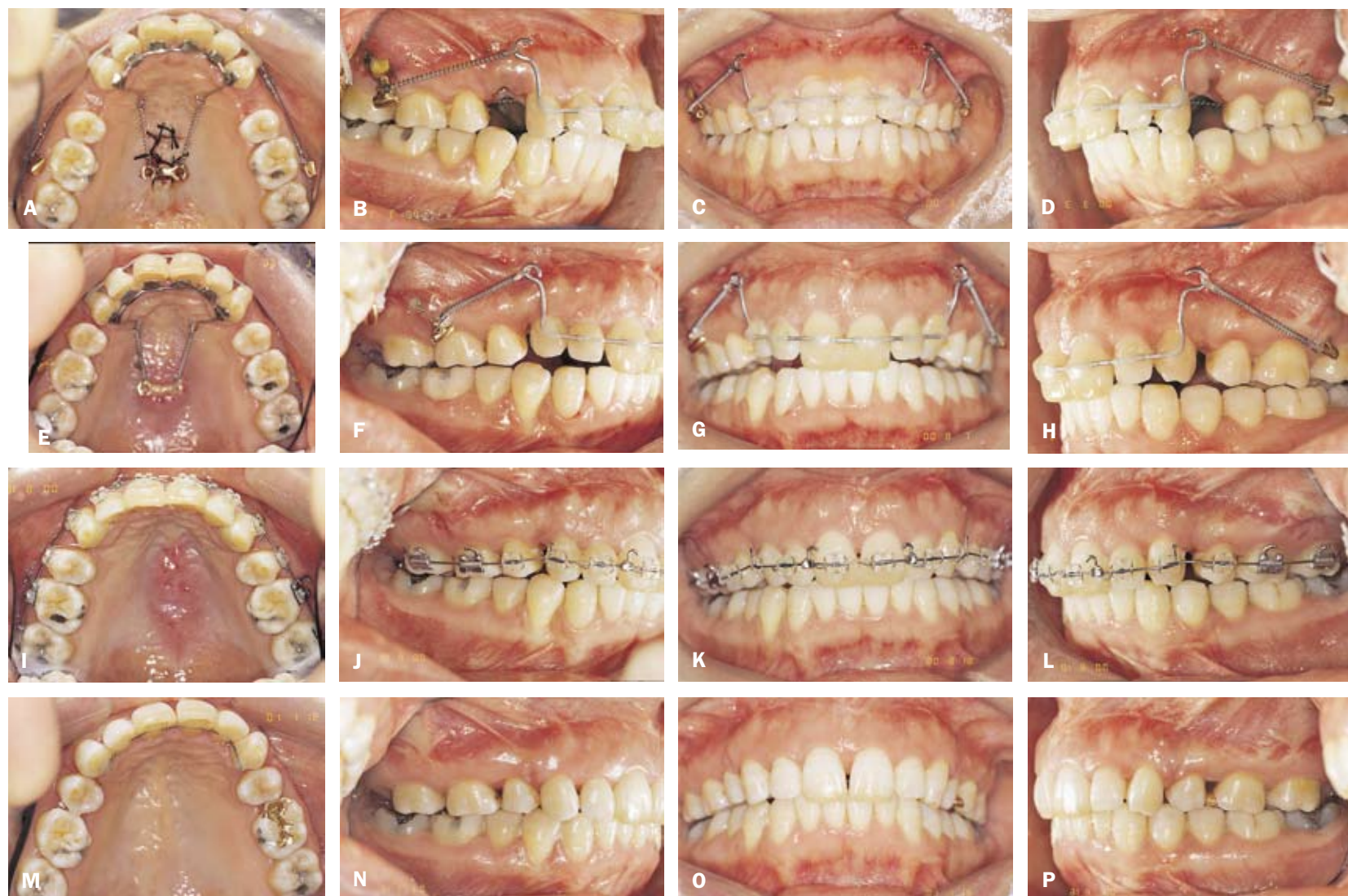


FIGURE 13-21 A through P, Progressive intraoral photographs from anterior retraction to posttreatment. The total orthodontic treatment period was 12 months: One month from upper perisegmental corticotomy (A through D); Upper anterior retraction was completed after 5 months from corticotomy (E through H); The C-plate was removed during finishing (I through L); The palatal soft tissue was healed in a few days, after debonding (M through P). Lower anterior intrusion was initiated after upper anterior retraction,



FIGURE 13-22 A through F, Posttreatment extraoral and intraoral photographs. The remaining extraction space was closed by restorative materials. Lateral cephalograms of pretreatment (G), after perisegmental corticotomy (H), after upper anterior retraction (I), and posttreatment (J). Note that anterior retraction was completed 5 months after perisegmental corticotomy. Panoramic radiographs shows that remarkable root resorption of the upper anterior teeth did not occur during treatment (K, L). Superimposition of cephalometric tracings pre-and posttreatment (M). Note that bending compression osteogenesis occurred during anterior retraction.

Complications: Swelling and Contusion

The severity of swelling or contusion after corticotomy depends on the suturing techniques, cold packs, location of surgical site, or physical constitution of the patient (Figure 13-23). If the complicated periroot corticotomy is performed for a patient who has frequently experienced a bruise or contusion, then extensive swelling or contusion can occur after the surgery. Those swellings and contusions, even spread over the

neck or around the eye, usually disappear over time.

A careful suturing can most effectively minimize these complications. Resorbable silk should be used to suture the inner layer, and complete hemostasis must be ensured by careful suturing. Complications after corticotomy on the labial side of the maxilla or mandible are more frequent than on the lingual side, so the patient needs to be instructed to use the cold pack and pressure dressing for 2 days.

Time of Treatment and Surgery

Generally, the Speedy Orthodontics for anterior retraction takes 4 to 6 months for anterior segment retraction after perisegmental corticotomy and 2 to 3 months for the finishing period. However, the finishing stages can be increased in the adult patient who shows severe midline deviation, tipped molars, and periodontal disease, and needs the molar protraction. A tooth positioner can shorten the finishing time and improve the occlusal interdigitation. The



FIGURE 13-23 A, D, Facial photographs taken 1 day after complicated upper labial perisegmental corticotomy and lower speedy anterior dentoalveolar segment osteotomy, performed for a 52-year-old female patient (Case S.H.C.) who has frequently experienced a bruise or contusion. Extensive swelling and contusion occurred. However, those swellings and contusions disappeared 10 days later (B, E). C, F, Facial photographs before debonding. The total treatment period was 10 months.

remaining extraction space can be closed by restorative dentistry.

Outpatient Feasibility

Many patients reject the use of general anesthesia. Therefore, outpatient corticotomy with local anesthesia is a viable alternative. Corticotomy for Speedy Orthodontics needs no general anesthesia, allows for a shorter operation time, produces fewer complications (bleeding, pain), and has a lower cost. It is performed easily as a routine clinical procedure with local anesthesia alone or in combination with conscious intravenous sedation. The treatment time is less than 1 hour in each surgery. Clinicians have observed that inadequate root deviation of the teeth to be moved does not affect the anterior segment retraction, and soft tissue adaptation is more easily predicted and controlled in the three dimensions during space closure after corticotomy, compared with orthognathic surgery.

Retention

The adaptation period for the tongue to adjust itself to the realigned dental arches is essential, because the tongue muscle can exert a force strong enough to move teeth. The patient needs to practice pronunciation while wearing removable retainers added to the lingual splinting with wire (Figure 13-24). Furthermore, the patient should be instructed to maintain the proper relationship between his/her upper and lower lips. It must be remembered that a nutritious diet is one of the most important factors in helping the damaged bone tissue heal.

Conclusion

Speedy Orthodontics can shorten the treatment duration, expand the boundary of adult orthodontic treatment, and increase posttreatment stability. The treatment objectives focus mainly on the speedy and simultaneous improvement of facial and dental esthetics and function, by

overcoming the anatomic limits set by the cortical plates of the alveolus at the level of the incisor apices that act as orthodontic walls. It gives the orthodontist the ability to retract the upper anterior dentition effectively without patient compliance, and to close the open bite by using force direction control.

However, orthodontists also need to address the limitations of Speedy Orthodontics, which include a vertical problem, and TMD. Further clinical research on the technical development of the corticotomy procedure is required for achieving the ideal upward and backward movement pattern of the maxillary anterior segment, and designing the therapeutic mechanisms applicable for optimal corticotomy-facilitated orthodontics.

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FIGURE 13-24 A, B, C, The wraparound retainer was additionally delivered after the maxillary and mandibular anterior teeth were splinted using resin-bonded wires. The purpose of the removable retainer is to intercept the tongue thrust and let the tongue adapt itself to the narrowed oral cavity.

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Optimizing Orthodontic Therapy with Dentoalveolar Distraction Osteogenesis

Scotty L. Bolding, Richard R. Roblee, George Sándor and Makepeace Charles

Traditional surgical orthodontic therapy uses cell-mediated orthodontic tooth movement to align teeth within the alveolar processes prior to orthognathic procedures.¹ Orthognathic procedures are used to align the skeletal structures of the face and orient the alveolar arches so that the teeth are positioned in proper molar and cuspid relationships. Treatment planning relies heavily on clinical assessment of facial defects and cephalometric analysis to determine these discrepancies. Once these discrepancies have been identified, appropriate skeletal movements are completed by the surgeon with procedures such as the sagittal split osteotomy and Le Fort osteotomy.

Although these procedures have experienced very favorable outcomes, there are many cases in which the facial deficit is not truly a skeletal problem but is an alveolar bone discrepancy.² The alveolar bone discrepancy may be either an intra-alveolar arch defect that does not allow enough room for the dentition or an alveolar-skeletal defect that does not align the alveolus properly with its associated skeletal structures.

Dentoalveolar discrepancies are difficult to treat with cell-mediated orthodontic tooth movement alone. Arch deformities usually require the orthodontist to prolong the orthodontic treatment time to obtain proper tooth alignment. Often this requires the extraction of multiple teeth or the positioning of the teeth outside the confines of their underlying bone. Traditional surgical procedures that have been used to correct arch width discrepancies are surgically assisted rapid palatal expansion and the mandibular midline distraction.³ Although these surgical procedures have provided favorable results, they do not assist in anterior-posterior or vertical discrepancies. Many of the anterior-posterior dentoalveolar discrepancies are treated with orthognathic surgical procedures even though the underlying skeletal foundation is in a

relatively normal position. One example of this is mandibular advancement in patients with mandibular alveolar deficiency. Often this can necessitate a reduction genioplasty to prevent overprojection of the mandible.

In 1959, Kole suggested that the greatest resistance to tooth movement is created by the cortical bone of the alveolus.⁴ He described the use of interdental corticotomies to facilitate accelerated orthodontic tooth repositioning in three dimensions. This procedure was described by many other authors^{5,6} but became less favorable owing to advancements in orthognathic surgery. With the recent decline in the number of orthognathic surgical cases being treatment-planned or accepted for a variety of reasons, there is a tremendous need to assist the orthodontist with alternative options that can augment orthodontic outcomes.⁷ In this chapter, we present a new concept that addresses dentoalveolar bony discrepancies with interdental osteotomies, distraction osteogenesis, and active orthodontics. This procedure is designed to change the dentoalveolar complex so that the teeth, dentoalveolar bone, and jaws are appropriately addressed to maximize ideal functional and esthetic relationships. This technique provides an adjunctive optional treatment to traditional orthognathic surgery and allows the oral and maxillofacial surgeon and orthodontist to treat underlying dentoalveolar defects without moving the skeletal complexes to correct these deformities.

Methods

Surgical Considerations

The use of corticotomies and osteotomies to rapidly move the dentition has developed from two principles: (1) weakening of the cortical bone-tooth interface and (2) distraction osteogenesis. The former was first suggested by Frost, an orthopedic surgeon, in his description of bone

repair⁸ and has since been studied and proposed as a method of accelerating orthodontic treatment by Wilcko and colleagues.² Physiologically, this theory proposes that when bone is injured or decorticated, an exuberant bone remodeling phase occurs in which teeth can be rapidly moved through demineralized bone. Frost coined this phenomenon *rapid acceleratory phenomenon* (RAP).⁸

The second physiologic principle involved in rapid tooth movement is distraction osteogenesis. The technique presented in this chapter uses distraction principles to accelerate tooth movement. Distraction osteogenesis has emerged as a technique that by its very nature allows changes to the vectors of growth and results in the genesis of new tissues.^{9,10} It is a rapidly developing area with applications in many areas of oral and maxillofacial surgery.

Distraction osteogenesis is a biologic process that promotes bone formation between the cut surfaces of bone segments that are gradually separated by incremental traction.¹¹ This process is initiated when traction is applied to separate the bony segments and continues as long as the tissues of the callus that forms between the segments are stretched. Bone formation occurs parallel to the direction or vector of distraction. On a large scale, this process also initiates histogenesis of the tissues surrounding the distracted bone: cartilage, ligaments, muscle, blood vessels, gingiva, and nerve tissue.^{3,12,13}

Dentoalveolar distraction osteogenesis (DDO) uses expanded orthodontic principles and combines them with the RAP and dentoalveolar distraction. This combination allows for the tooth to be used as a handle to move the alveolar segment in relation to the skeletal foundation. In addition, the RAP may further enhance and accelerate cell-mediated tooth movement.

DDO involves horizontal corticotomies separating the teeth from their bony base and

vertical osteotomies separating tooth-bearing dental segments. The vertical osteotomy is usually placed between the teeth in the interradicular bone and usually requires minimal spacing between the teeth. To avoid destruction and tooth loss, each dental segment must be isolated within its periodontium and bone. Current techniques using fine osteotomes, oscillating saws, and, more recently, the piezosurgical knife allow precise segmentalization of alveolar segments, with no obvious root resorption observed to date. The horizontal corticotomy is completed through the buccal cortex just apical to the root apices. This process is less likely to directly denervate the tooth. The individual bony blocks and associated teeth are then distracted and mobilized by active orthodontic mechanics.

Orthodontic Considerations

When using DDO, the orthodontist must modify some of the traditional approaches depending on the type of alveolar problem. If the discrepancies are primarily intra-alveolar (such as severe crowding), the DDO surgery should be performed within 2 weeks of the appliances being placed. This maximizes the alveolar correction of DDO and minimizes the negative compromises from cell-mediated tooth movement in a deficient alveolus. When the underlying problem is an alveoloskeletal discrepancy (such as dentoalveolar retrusion), the DDO surgery should be performed after some orthodontic leveling and aligning have been completed. This allows the orthodontist to immediately use more rigid arch wires to better control the alveolar segments when changing their relationships with the skeletal base. This control is especially true when combining DDO with absolute anchorage (dental implants, mini-implants, and plates) to further change the alveoloskeletal relationships. When there are combination problems involving both intra-alveolar and alveoloskeletal discrepancies, the providers need to plan when the DDO surgery should be performed to best address the problems or plan a multiple-stage DDO surgery.

Owing to rapid movement of the dentoalveolar segments after DDO surgery, orthodontic adjustments should be performed weekly or biweekly depending on the nature of the forces being used. This short interval appears to maximize the speed of changes and helps prevent complete healing of the osteotomy sites and prolong the DDO effect.

Advantages

DDO

1. Allows for the true correction of the dentoalveolar arch discrepancies without more advanced skeletal surgeries.
2. Accelerates the orthodontic treatment time required to complete the occlusion. We

usually estimate approximately half the time the case would take with traditional orthodontics.

3. Promotes optimal dentofacial esthetics when the primary deficiency is the dentoalveolar complex.
4. Has less morbidity and less recovery time than orthognathic surgical procedures (performed in an outpatient setting).
5. Costs less than traditional orthognathic surgery, which allows greater access to the procedure by the public.
6. Allows for treatment of patients with previous root resorption.
7. Is a less invasive procedure than traditional orthognathics and can be performed in an outpatient office setting to decrease the cost of delivery.

Contraindications

1. Active periodontal disease or dental disease
2. Patients with uncontrolled diabetes or who are immunocomprised
3. Patients unwilling to undergo orthodontic treatment
4. Insufficient attached gingiva, which may lead to defects in the papillary area

Technique

The patient requires orthodontic appliances to be applied with an active wire prior to the surgery. The procedure is usually done under general anesthesia or intravenous sedation. The patient is prepared and draped in the usual fashion for intraoral osteotomies. An envelope flap is elevated on the buccal aspect of the maxilla and mandible using a sulcular or vestibular incision (Figure 14-1). The sulcular incision is completed from the anterior aspect of each quadrant to the

most distal aspect of the most posterior tooth with lateral releasing incisions to facilitate access (Figure 14-2). If a vestibular incision is to be used, it can be placed 5 mm superior to the junction of the attached and unattached mucosa from the anterior aspect of the arch to the zygomaticomaxillary buttress. The efficacy of a vestibular incision for orthognathic surgical procedures is well documented; however, if there is minimal attached tissue or a friable papilla between the teeth that will need to be undermined if you use a vestibular incision, then the sulcular incision may prevent loss of the papilla (Figure 14-3). The periodontal health and architecture can remain unchanged with this type of incision given the appropriate surgical technique. The lingual tissues are usually not elevated as this may compromise blood supply to the tooth-bearing segments. In some cases, the lingual tissues have been released to simultaneously remove tori without compromise to the alveolar segment. A small-taper fissured or round bur is used to begin the osteotomies between the roots of all treated teeth (Figure 14-4). A



FIGURE 14-2 The intrasulcular incision.



FIGURE 14-1 Flap designs may be intrasulcular or vestibular.

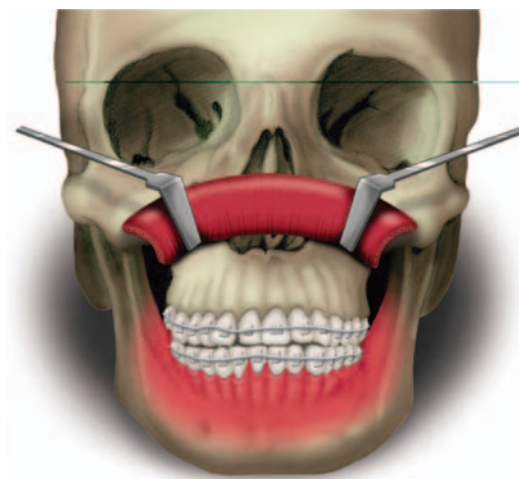


FIGURE 14-3 Reflection of the flap for access to the dentoalveolar arch.

rounded osteotome is used to complete the vertical osteotomies from the buccal to the lingual cortex (Figure 14-5).

More recently, a piezosurgical knife (Figure 14-6) has been used to complete the osteotomy

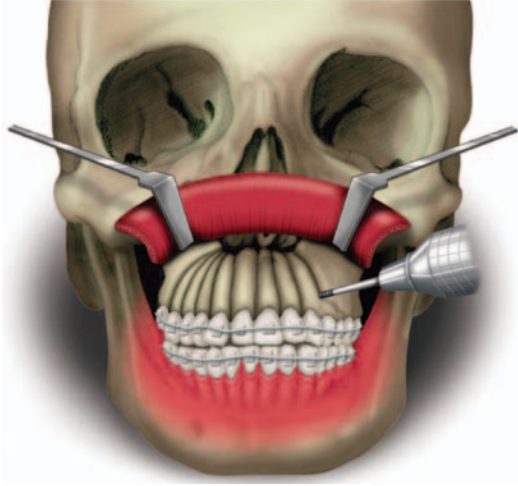


FIGURE 14-4 Interdental corticotomies with a tapered fissured bur.

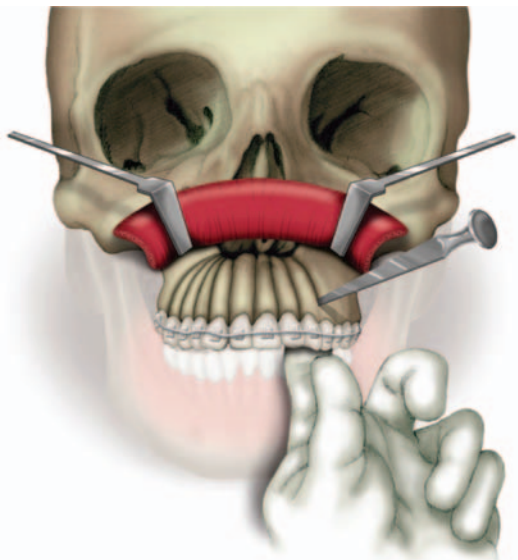


FIGURE 14-5 Completion of the osteotomy, protecting the lingual flap with digital palpation.

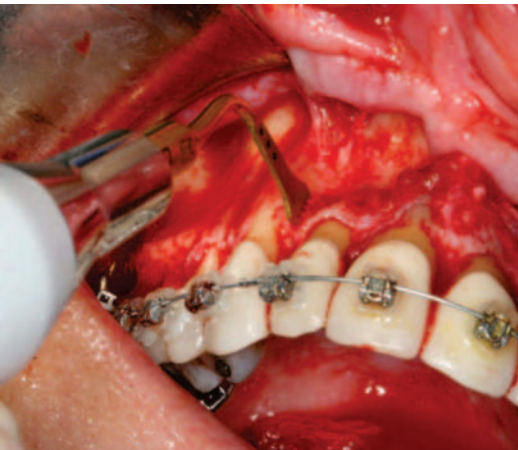


FIGURE 14-6 Piezosurgical knife.

without the use of the osteotome.^{14,15} This technology allows for protection of the tooth and its associated soft tissue structures.

Apical corticotomies are completed using a thin-taper fissured bur through the buccal cortex to divide the tooth-bearing segments from their bony base. The segments are mobilized with the lingual periosteum left intact (Figure 14-7).

If segments are to be intruded, a wedge of bone can be removed at the apical extent of the vertical osteotomies within the buccal bone (Figure 14-8). To intrude, extrude, or significantly mobilize a segment, dissection can be carried superiorly on the maxilla or inferiorly on the mandible to place an anchorage plate or temporary anchorage screw (Figure 14-9). Elastics can be tied to these L plates or screws to aid in movement.

Freeze-dried demineralized allogeneic bone can be applied to surgical sites in areas in which facial bone is thinning owing to poor arch alignment or alveolar bone discrepancies. We

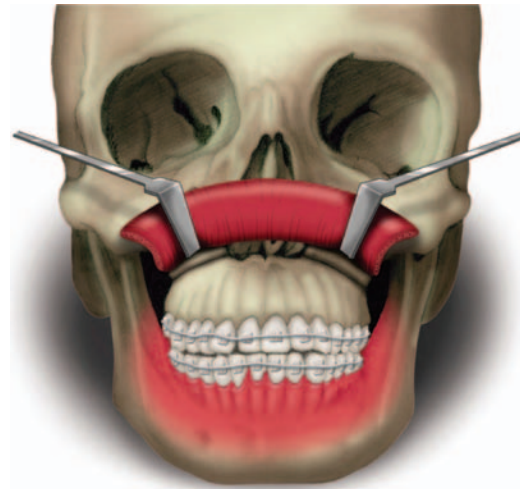


FIGURE 14-7 Horizontal corticotomy.

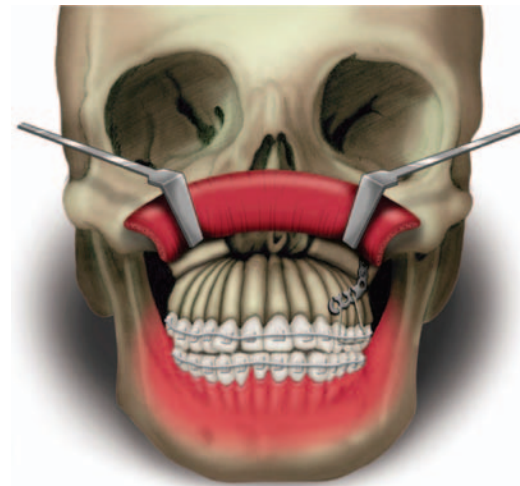


FIGURE 14-8 L plate used for intrusion mechanics.

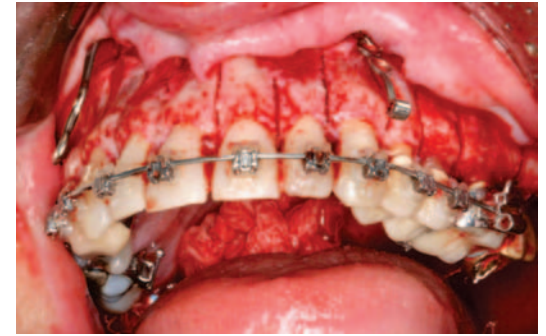


FIGURE 14-9 Dentoalveolar distraction osteogenesis with an anchoring plate.

have noticed that the use of platelet-rich plasma has decreased the amount of postsurgical ecchymosis and has been shown to promote bone healing; therefore, we use platelet-rich plasma on the osteotomy sites and under the flap prior to closure.¹⁶ The flaps are reapproximated and closed with 4-0 or 5-0 chromic gut sutures in a vertical mattress configuration (Figure 14-10).

Active light orthodontic tooth movement will begin at the time of the surgery owing to the active wire, but, generally, the activation and changing of the wires begin after a 3- to 5-day latency period, in accordance with distraction principles. Published distraction regimens (0.5 mm/d) are used to safely move bone

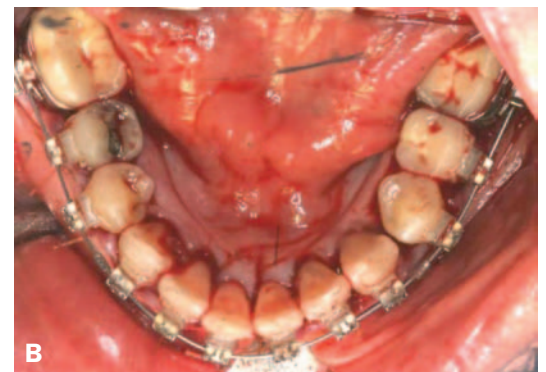


FIGURE 14-10 A, Presurgical. B, Immediate results after dentoalveolar distraction osteogenesis.

segments with minimal risk of devitalization.¹² The arch wire is changed weekly or biweekly until the desired tooth movement is achieved. During the orthodontic phase, it is important to keep the teeth moving to maximize the effects of the surgical assistance. Once the teeth are aligned and positioned properly, a consolidation period of several weeks is required to allow ample time for bone healing.

Clinical Case Reports

Case 1. Figure 14-11

This 22-year-old female presented with a chief complaint of “deep bite and jaws pop & hurt”. Her past medical history was unremarkable and she was not under medical care. She was

on a 6-month routine dental and periodontal maintenance schedule.

Clinical Findings Figure 14-11 A-E

- Excessive smile line, canted incisal plane, and excessive incisor exposure with lips in repose
- Unstable and traumatic interincisal relationships with excessive horizontal and vertical overlap
- Retroclined maxillary and mandibular incisors
- Severe asymmetrical dentoalveolar extrusion of maxillary and mandibular anterior dentitions
- Class II dental malocclusion
- Mild maxillary transverse deficiency

Treatment Plan Figure 14-11 F-I

- Custom indirect setup and bond maxillary and mandibular orthodontic brackets
- Maxillary DDO surgery and anchorage plate in anterior maxilla to:
 - slightly expand maxillary dentoalveolar complex
 - asymmetrically intrude anterior maxillary dentoalveolar complex to enhance function and anterior esthetics
 - enhance and significantly accelerate orthodontic therapy
- Orthodontically level lower arch
- Class II orthodontic mechanics
- Maintain interincisal relationship with nighttime centric relation splint Figure 14-11 O



FIGURE 14-11 Case 1 A-E, Initial. F-I, Progress. J-N, Final. O, Night guard used for vertical and overall retention.

Case 2 Figure 14-12

This forty-eight-year-old female presented with a chief complaint of “the alignment of my bite is wrong and I am wearing away my enamel.” The past medical history was significant for thyroid trouble for which the patient was taking Levoxyl. The patient’s dental history was routine with a reported bruxism habit. .

Clinical Findings Figure 14-12 A-G

- Anterior divergent, concave profile with insufficient lip support and a strong chin button
- Mildly prognathic mandible compensated by #21 and 28 extractions and mandibular dentoalveolar retrusion
- Retroclined maxillary and mandibular incisors
- Class III molar and Class II canine dental malocclusion with excessive horizontal and vertical overlap

Treatment Plan Figure 14-12 H-T

- Custom indirect setup & bond maxillary and mandibular orthodontic brackets
- Level and align arches
- Procline maxillary and mandibular incisors
- Mandibular DDO surgery to facilitate:
 - opening implant sites #20 and 29
 - correcting malocclusion
 - reversing mandibular dentoalveolar retrusion
- Restorative therapy to replace compromised crowns and restore implants



FIGURE 14-12 Case 2 A-G, Initial. H-J, Pre-surgical orthodontics. K&L, Initial and pre-surgical overjet comparison.



FIGURE 14-12 Case 2 continued. M-T Progression of treatment. U, Pre-debond panorex. V-Z, Case comparison. Note enhanced smile and lip support.

Case 3 Figure 14-13

This 40-year-old female presented with a chief complaint of “I need my teeth fixed.” Her past medical history was unremarkable and she was not under medical care. The patient was not taking any medications and had no previous surgical history. The patient had a positive history for a tongue thrust and previous comprehensive orthodontic therapy with compromised results due to dentoalveolar deficiencies and severe root resorption. All of her incisors were given a hopeless prognosis by her previous providers and they strongly recommended that she was not to have any more orthodontic therapy. She was on a 6-month routine dental and periodontal maintenance schedule.

Clinical Findings Figure 14-13 A-G

- Maxillary transverse deficiency with dental compensations and excessive buccal corridors
- Dentoalveolar vertical deficiency in anterior maxilla with reverse smile line and insufficient incisor exposure with lips in repose (°2mm)
- Posterior divergent and convex profile with the appearance of midface deficiency and a retrognathic mandible
- Insufficient upper and lower lip support with a mildly everted lower lip and a deep labialmental sulcus

Treatment Plan Figure 14-13 H-O

- Custom indirect setup and bond maxillary and mandibular orthodontic brackets
- Maxillary and mandibular DDO surgery to:
 - minimize root resorption secondary to orthodontic therapy
 - expand and slightly advance maxillary dentoalveolar complex
 - extrude anterior maxillary dentoalveolar complex to enhance function; anterior esthetics and setup for future possible dental implants
- Protract lower dentition to improve occlusion and lower lip support
- Permanent fiber-reinforced lingual retainers to stabilize and maintain incisors as long as possible Figure 14-13 R&S
- Future implant therapy if incisors are lost

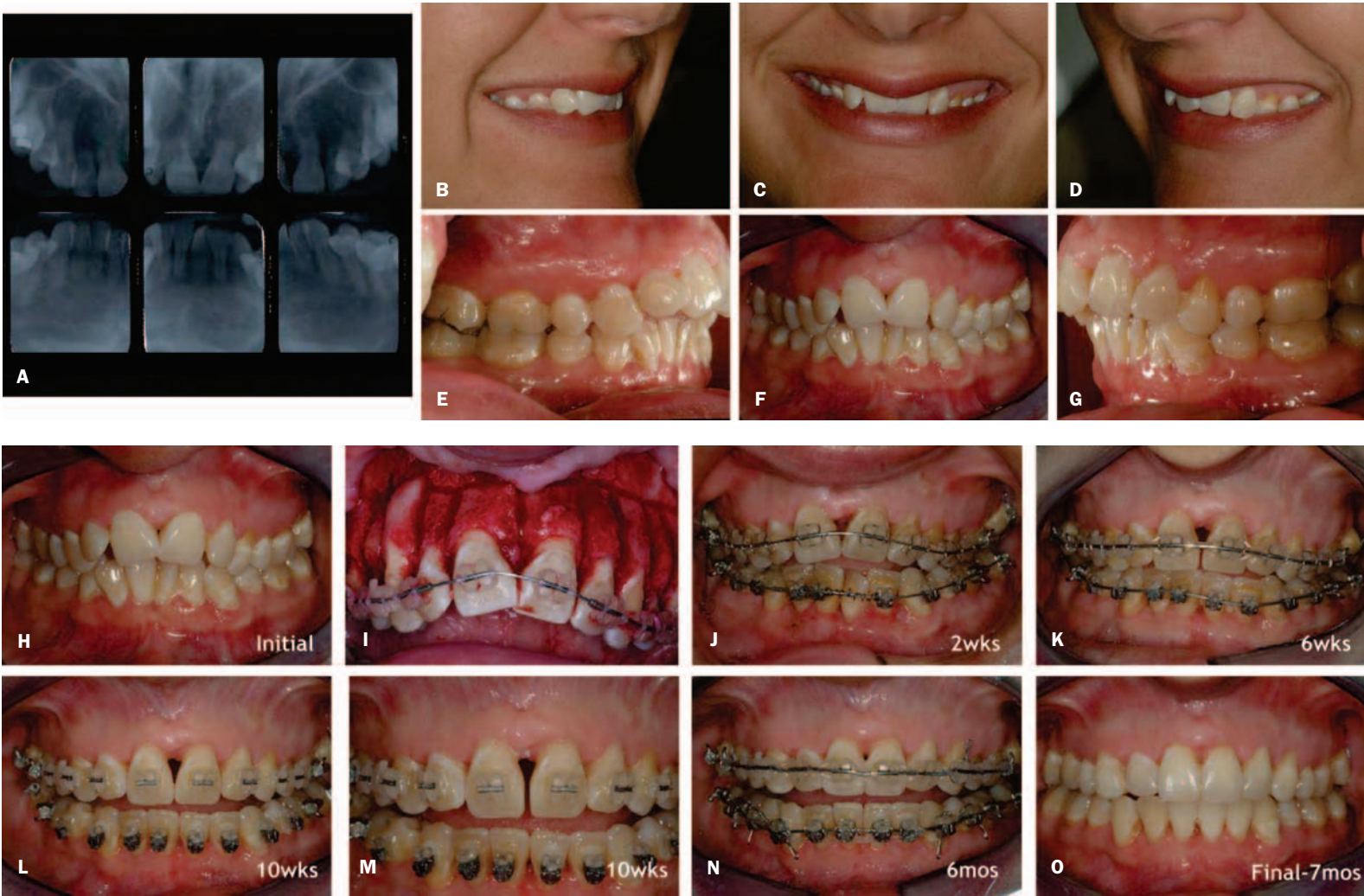


FIGURE 14-13 Case 3 A-G, Initial. H-O Progression of treatment.

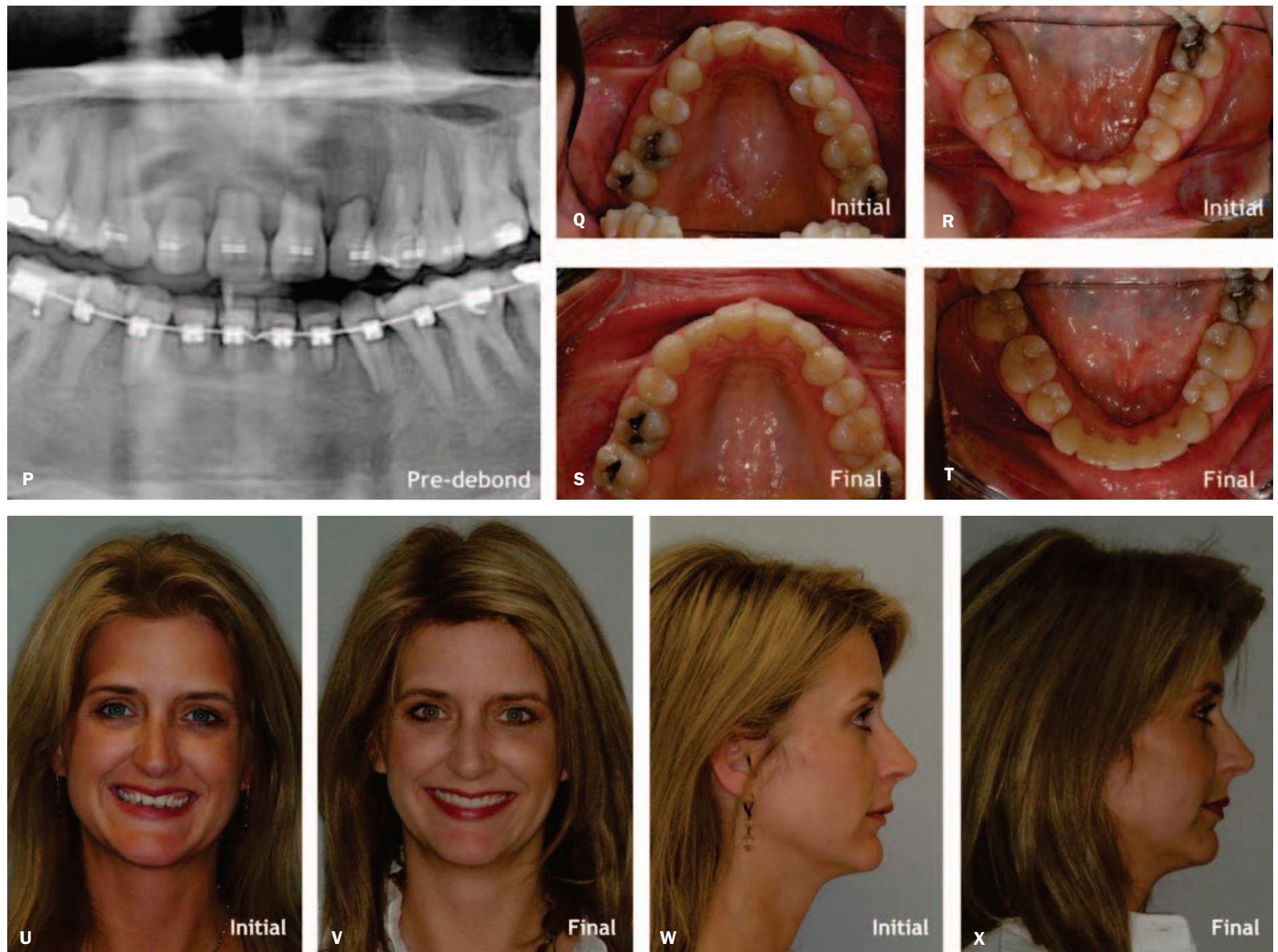


FIGURE 14-13 Case 3 continued. P, Pre-debond panorex showing minimal progression of root resorption. Q-X, Before and after case comparison.

Case 4

This 40-year-old female presents with a chief complaint of “ my teeth don’t line up.” She had been trying to have bimaxillary orthognathic surgery for years but she could not afford it and could not get insurance coverage. Her past medical history was not significant and she was not taking any medications. The dental history was routine.

Clinical Findings Figure 14-14 A-H

- Severe maxillary transverse deficiency with dental compensations and excessive buccal corridors

- Severe skeletal and dentoalveolar asymmetries
- High mandibular plane angle with increased lower face height
- Full upper and lower lip support due to bimaxillary dentoalveolar protrusion with no labial mental sulcus

Treatment Plan Figure 14-14 A-H

- Custom indirect setup and bond orthodontic brackets and insert SARPE
- Maxillary (#7–10) and mandibular DDO surgery

- Osteotomies to assist RPE
- Enamelplasty as needed to idealize tooth form and close “black triangles” Figure 14-14 O
- Retract lower left dentition with mini-implant to improve occlusion and reduce lower lip support Figure 14-14 P
- Permanent fiber-reinforced lingual retainers Figure 14-14 N
- Periodontal grafting as needed
- Sliding genioplasty to reduce vertical and align chin with facial midline

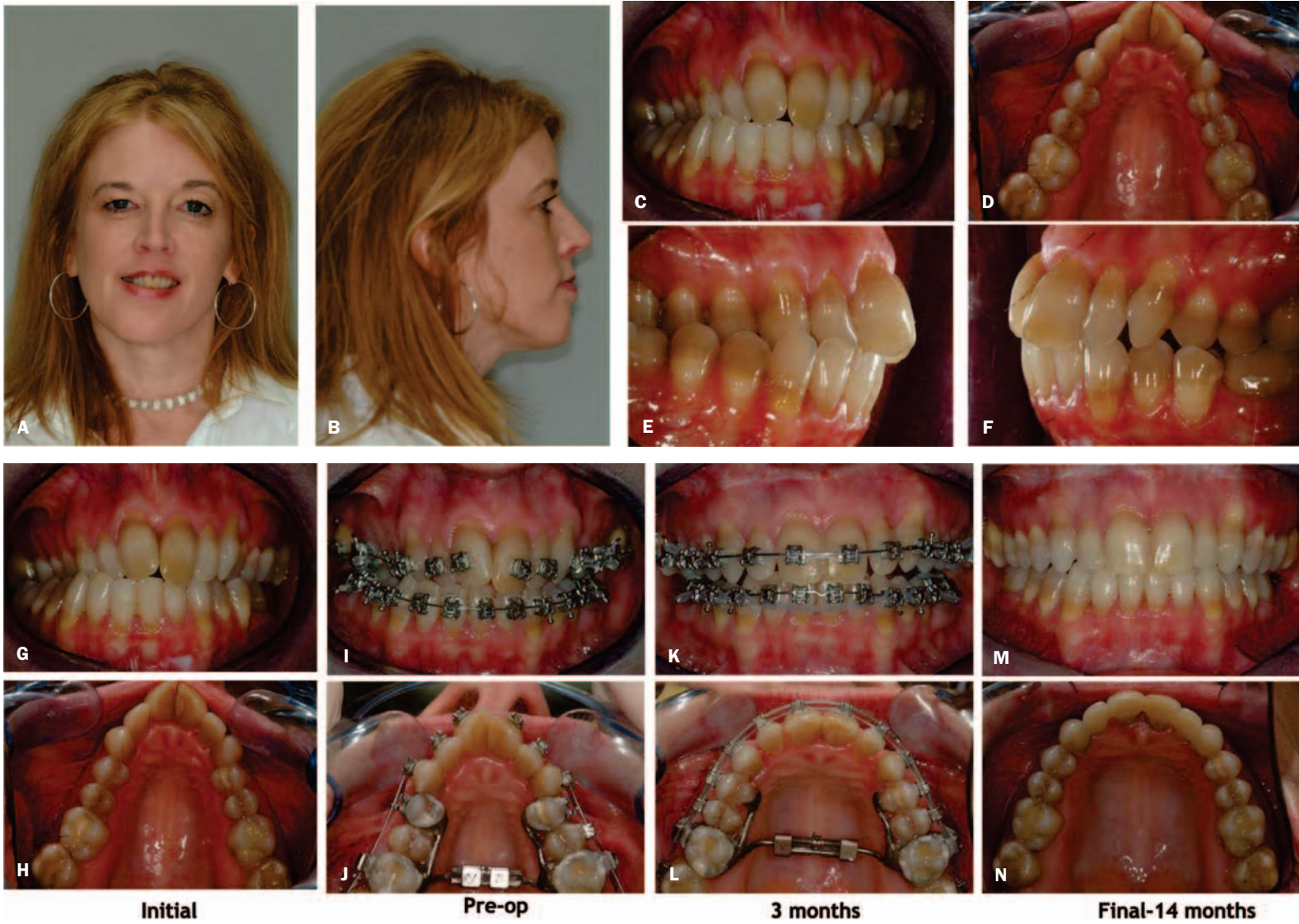


FIGURE 14-14 Case 4 A-H, Initial. G-N Progression of treatment.



FIGURE 14-14 Case 4 continued. O, Reshaping of incisors to shorten and to close “black triangles.” P, Mini-implants were used for anchorage to retract mandibular dentition to correct Class III dental relationship. Q-Z, Case comparison. Patient will have gingival grafting and genioplasty procedures in future.

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Selective Alveolar Decortication for Rapid Surgical-Orthodontic of Skeletal Malocclusion Treatment

Donald J. Ferguson, William M. Wilcko and M. Thomas Wilcko

Orthodontic tooth movement can be accelerated to diminish treatment time by 60 to 70% without compromising the treatment outcome. Wilcko and colleagues demonstrated safe and rapid orthodontic tooth movement following selective labial and lingual decortication of alveolar bone in the area of desired tooth movement.¹ Cases of moderate dental arch crowding are completed in 4 to 6 months of active orthodontic treatment with this technique, and the results have been shown to be remarkably stable.²

Selective Alveolar Decortication Combined with Orthodontic Treatment

The use of corticotomy to correct malocclusion was first described in 1892 by L.C. Bryan and Cunningham in 1893, but it was Heinrich K  le in 1959 who re-introduced alveolar corticotomy to resolve malocclusion.³ He performed interdental alveolar corticotomy surgery, leaving the medullary bone intact, combined with a through-and-through osteotomy above the apex of the teeth. Generson and colleagues, in 1978, modified the K  le method by eliminating the subapical osteotomy and described treatment of open-bite malocclusion using selective alveolar decortication and orthodontics.⁴ Subsequently, multiple authors reported rapid tooth movement after alveolar decortication and explained the changes as "bony block" movement.⁵⁻⁷

In 2001, Wilcko claimed that decortication combined with augmentation grafting created greater alveolar volume,² which eliminated bony dehiscences and fenestrations under most circumstances and likely enhanced the stability of the orthodontic treatment result. They patented and trademarked their technique as the Periodontally Accelerated Osteogenic Orthodontics (PAOO, Wilckodontics, Inc., Erie, PA) procedure.

Following full-thickness labial and lingual alveolar flaps, decortication surgery was performed around the teeth intended for movement, with bone cuts made barely into the medullary bone, taking care not to injure any tooth or encroach upon the periodontal ligament. How the bone was injured with a surgical bur had more to do with selecting the thicker parts of cortical bone rather than satisfying any particular preconceived pattern (Figure 15-1). Thicker portions of the alveolar cortex were selectively traumatized to promote bleeding. Resorbable grafting materials wetted with an antibiotic solution were applied directly over the activated

bone, and the flaps were sutured into place using Gore-Tex suture material (Figure 15-2). A frequently used grafting mixture was demineralized freeze-dried bone (DFDBA) and bovine bone wetted with clindamycin phosphate solution (0.5 mg/ml). Alveolar grafting also benefits the patient by repairing bony dehiscences and fenestrations (Figure 15-3). In the Wilcko protocol, fixed orthodontic appliances were placed and tooth movement was initiated during the week prior to the decortication surgery, and the orthodontic appliances were activated approximately every 2 weeks thereafter until orthodontic treatment was completed.



FIGURE 15-1 The technique for alveolar decortication is based more upon cortical bone thickness than upon any particular preconceived pattern of bone injury with a surgical bur, such as cuts or dots or a combination of cuts and dots. The surgical scarring should barely penetrate the cortical bone into the medullary space in the area of desired tooth movement on both the labial-buccal and lingual surfaces. Reproduced with permission from Drs. W.M. Wilcko and M.T. Wilcko.



FIGURE 15-2 Resorbable grafting materials wetted with an antibiotic solution such as clindamycin phosphate, are applied directly over the activated bone. A frequently used augmentation grafting mixture is two-parts demineralized freeze-dried bone (DFDBA) and one-part bovine bone applied at a rate of 0.5 to 1 cc of grafting mixture per tooth to be moved.

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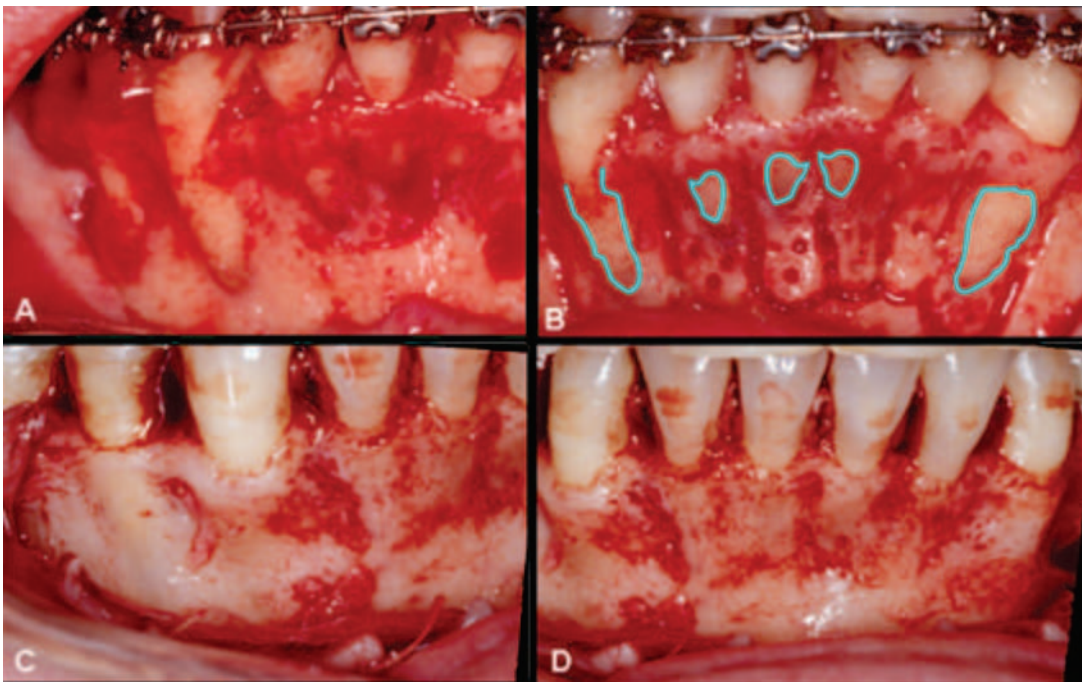


FIGURE 15-3 Augmentation alveolar grafting repairs bony dehiscences and fenestrations. A, evidence of bony discrepancies after full-thickness flap. B, Decortication prior to grafting with dehiscences and fenestrations outlined. C, D, Absence of dehiscences and fenestrations 7.5 years after Periodontally Accelerated Osteogenic Orthodontics decortication and grafting.

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Selective Alveolar Decortication Technique Rationale

Selective alveolar decortication initiates normal healing processes and stimulates trabecular bone turnover adjacent to the surgical injury. A direct correlation between degree and proximity of bone trauma and intensity of physiologic healing response was described by Frost, which he coined Regional Acceleratory Phenomena (RAP).⁸ RAP begins within a few days of the insult, typically

peaks at 1 to 2 months, and may take as long as 2 years to completely subside.⁸ Bogoch and colleagues made a penetrating surgical incision into the head of the tibia in rabbits and studied the healing response adjacent to the surgical wound. They found a five-fold increase in medullary bone turnover adjacent to the corticotomy site.⁹ Buchanan and colleagues documented a similar observation in alveolar bone following tooth extraction, as did Yaffe and colleagues after alveolar periosteal flap elevation, and Verna and

colleagues after tooth movement.¹⁰⁻¹² Sebaoun and colleagues have demonstrated in laboratory rats that alveolar trabecular bone adjacent to labial and lingual corticotomy undergoes a three-fold increase in regional bone turnover at 3 weeks after decortication.¹³ High medullary bone turnover in healthy tissues results in new bone formation and low bone density, which are conditions that promote rapid tooth movement (Figure 15-4).

There are three tissue engineering principles associated with the selective alveolar decortication technique. First, decortication surgery initiates local tissue repair and the production of osteoprogenitor cells (signaling and angiogenesis) and osteoinductive agents (mostly from the hemorrhage). Second, low turnover tissues are replaced with high turnover tissues that are functionally normal, a reversible condition often referred to as osteopenia (diminished bone density but not bone volume). Lastly, high tissue turnover is promoted in a precise anatomic area; that is, immediately adjacent to the area of desired tooth movement. The tissues formed in the alveolus surrounding the area of desired tooth movement respond efficiently to biomechanical forces, and teeth move rapidly. Medullary bone osteopenia is highest nearest the decortication sites, and as long as the teeth continue to move, complete alveolar recalcification is not possible.

Pham-Nguyen and colleagues studied the three-dimensional volume of periodontal tissues surrounding the upper first molar in the rat model, following buccal and lingual selective decortication plus tooth movement.¹⁴ Using the Micro-CT technology, a significant decrease in alveolar mineralization became evident by 7 days after decortication, and the tooth movement prolonged the osteopenic effect induced by the selective decortication (Figure 15-5).

In clinically induced osteopenia, radiographic evidence demonstrates a marked reduction in trabecular bone density in the first 4 to 6 weeks after decortication. It is our observation that the rarefied spongiosa eventually recalcifies, and normal trabecular bone returns radiographically (Figure 15-6). Our clinical experiences verify that rapid tooth movement becomes clinically apparent at about 1 month after selective decortication.

Use of selective alveolar decortication technique resolves one fairly common patient grievance, "I want braces but the 2-year treatment time is unacceptable." This therapy, when prompted by the patient and offered as an adjunct to routine orthodontic care, decreases active orthodontic treatment by 60 to 70%. Decortication should not be used when the patient supports or represents any of the following conditions: (1) active periodontitis or diseased periodontal tissues, (2) uncontrolled

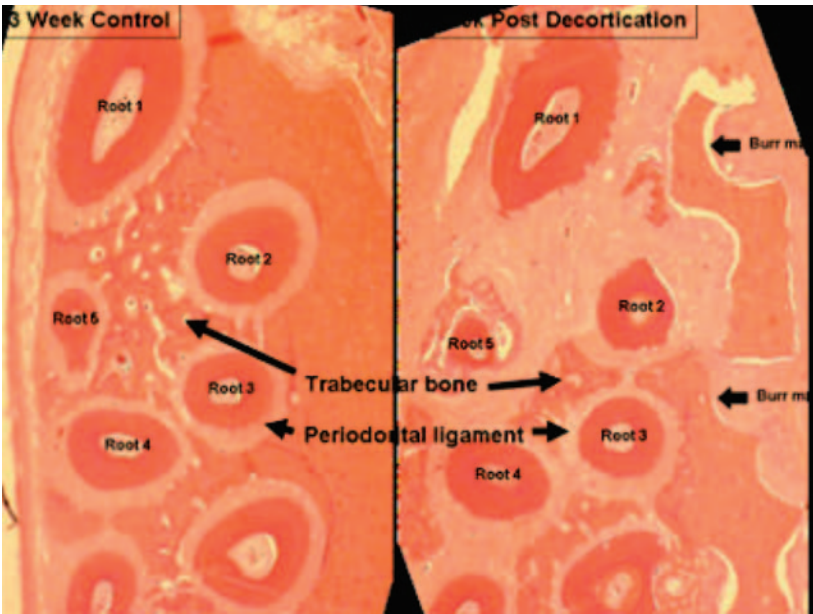


FIGURE 15-4 Status of alveolar bone surrounding the first molar of the rat at 3 weeks after decortication versus control. Hematoxylin-eosin staining demonstrates a marked decrease in calcified trabecular bone after decortication. Reproduced with permission from Sebaoun JD et al.¹³

osteoporosis or other bone diseases, (3) long-term use of medications that are antiinflammatory, immunosuppressive, or steroids, and (4) long-term use of biphosphonates.

Selective Alveolar Decortication for Treatment of Skeletal Malocclusion

The scope of orthodontic tooth movement into stable long-term positions is expanded following selective alveolar decortication. Proffit has indicated that there are limits of orthodontic tooth movement in the adult patient.¹⁵ For the upper central incisor, he has suggested the following: retract, 7 mm; protract, 2 mm; extrude, 4 mm; intrude, 2 mm. For the lower central incisor, Proffit has suggested the following: retract, 3 mm; protract, 5 mm; extrude, 2 mm; intrude, 4 mm.

Following selective alveolar decortication, the limits of orthodontic tooth movement in the adult patient are expanded. For the upper central incisor, the following limits are suggested: retract, 8 mm; protract, 5 mm; extrude, 10 mm; intrude, 5 mm. For the lower central incisor, the following limits are suggested: retract, 4 mm; protract, 9 mm; extrude, 6 mm; intrude, 7 mm (Table 15-1 and Figure 15-7)

The scope of treatment limits cannot be achieved using selective alveolar decortication, especially in the treatment of malocclusions that require moving the jaws anteriorly or posteriorly. However, the PAOO can be very helpful in preparing the dental arches for traditional orthognathic surgery (Figure 15-8). The scope of dental arch crowding treatment can be increased about three-fold using the PAOO, with stable results, as illustrated in Figure 15-9.

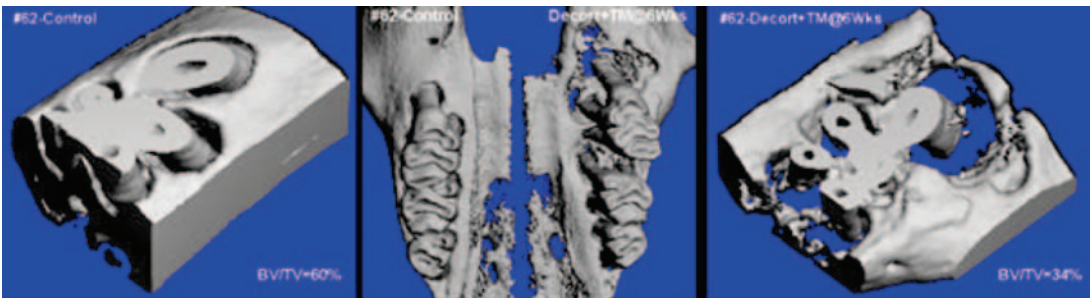


FIGURE 15-5 Micro-CT analysis of osteopenia at 6 weeks following selective alveolar decortication, and tooth movement showing gross specimen no. 62 (center), control side (left) and decortication plus tooth movement sides (right). On the experimental side, the bone volume (BV) to total volume (TV) ratio decreased to 34% compared with 60% on the control side, demonstrating transient alveolar osteopenia. Reproduced with permission from Pham-Nguyen K et al.¹⁴

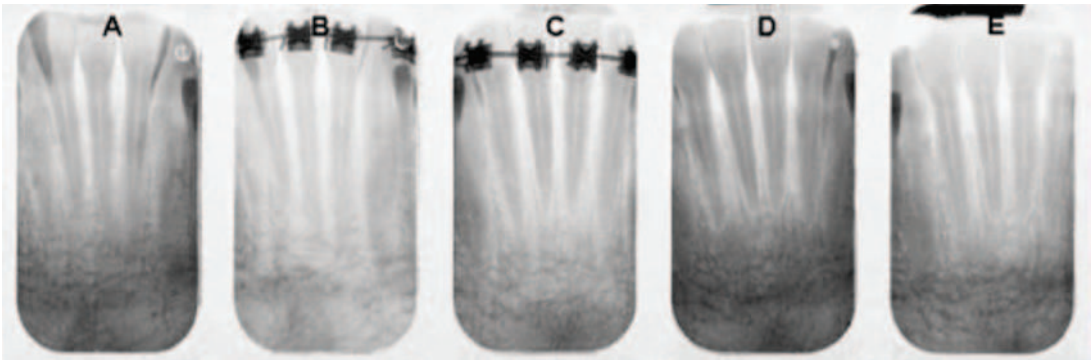


FIGURE 15-6 Periapical radiographs of a 39-year-old adult female patient demonstrating rarefaction of osseous images B and C (osteopenia) following labial-lingual corticotomy surgery (without grafting): pretreatment (A); 7 days after the corticotomies (B); 1 month and 10 days after the corticotomies (C); 10 days after orthodontic debanding, and 4 months and 24 days after the corticotomies (D); 3 years and 3 months after orthodontic debanding (E). Reproduced with permission from Drs. W.M. Wilcko and M.T. Wilcko.

Table 15-1 Limits* of Tooth Movement in the Adult for Permanent Upper and Lower Incisors with Orthodontics Only (after Proffit) Compared to Orthodontics Following Alveolar Decortication				
	Upper Incisor		Lower Incisor	
	Orthodontics Only	Decortication + Orthodontics	Orthodontics Only	Decortication + Orthodontics
Retraction	7	8	3	4
Protraction	2	5	5	9
Extrusion	4	10	2	6
Intrusion	2	5	4	7

*Note that the limits increase 2× to 3× in all planes of space except incisor retraction.

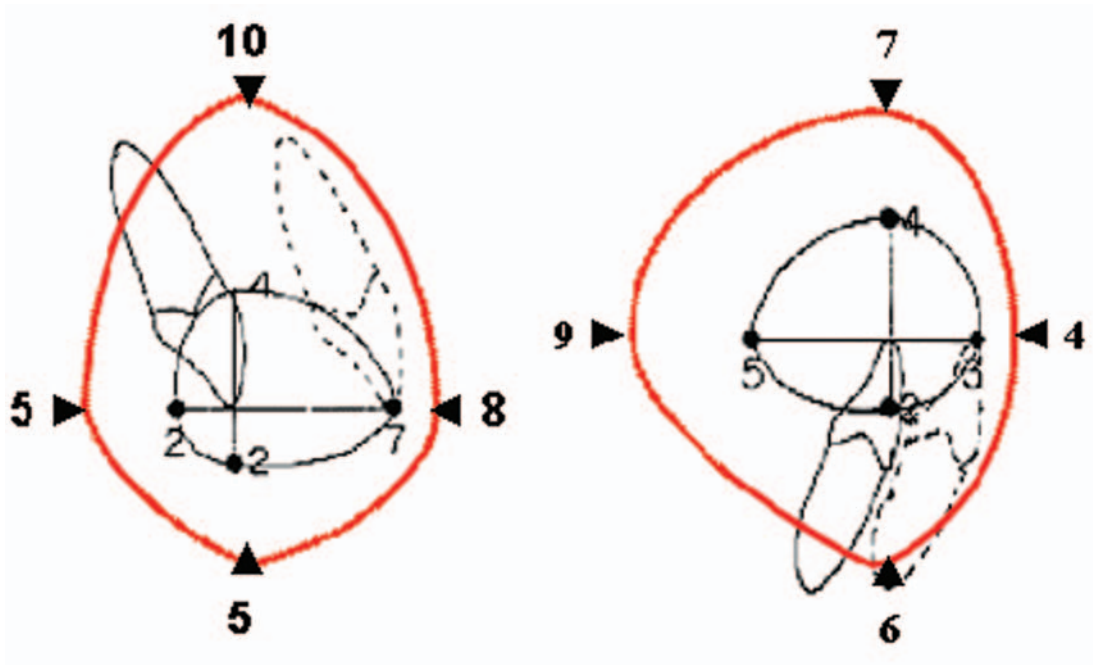


FIGURE 15-7 Suggested limits of orthodontic tooth movement into stable positions comparing orthodontics only (after Proffit) and orthodontics combined with selective alveolar decortication. Note that limits are 2 to 3 times greater for central incisor protraction, extrusion, and intrusion but not for incisor retraction.

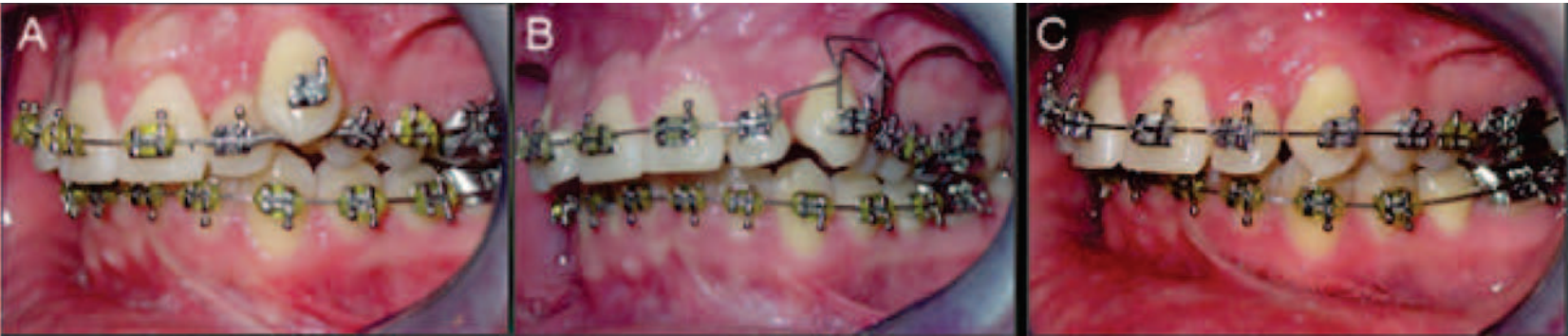


FIGURE 15-8 Rapid resolution of severe upper crowding showing immediate pre-Periodontally Accelerated Osteogenic Orthodontics (PAOO) (A), 2 months after decortication and augmentation grafting (B), and 4 months after PAOO that was immediately prior to mandibular advancement surgery (C).



FIGURE 15-9 Pretreatment, immediate posttreatment, and 4 years after debanding following Periodontally Accelerated Osteogenic Orthodontics (PAOO) from maxillary cuspid to cuspid for resolution of severe upper dental arch crowding prior to traditional mandibular advancement surgery (BSSO); the active treatment time was 9 months. Stability of the orthodontic outcome following resolution of severe upper anterior crowding is likely due to loss of tissue memory after PAOO and the increase in cortical bone thickness due to augmentation grafting.



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Miniature Implants and Retromolar Fixtures for Orthodontic Anchorage

W. Eugene Roberts, Ryuzo Kanomi and William F. Hohlt

Dental implants are important orthodontic adjuncts for extending the scope of biomechanical therapy and enhancing clinical outcomes. Endosseous implants and osseous screws have been used for orthodontic anchorage for over 60 years.¹ However, reliable prosthetic and retromolar devices, based on the technology introduced by Braanemark, have an approximately 20-year clinical history.²⁻⁵

Over the past decade, palatal anchorage devices such as endosseous screws and subperiosteal “onplants” have evolved.^{6,7} Over the same period, a number of systems featuring intra-alveolar miniscrews and microscrews have been developed. Building on an extensive clinical experience with microscrews, Kanomi developed a two-stage mini-implant method (K1 System) that was designed to osseointegrate (achieve rigid fixation within bone).⁸ Clinical experience has demonstrated strengths and weaknesses for all of the implant anchorage devices in the orthodontic armamentarium. Additional research is needed to provide clear indications and contraindications for each type of implant anchorage.

All of the currently available orthodontic anchorage devices have unique surgical and abutment requirements. Following a presentation of two applications of the well-established retromolar anchorage method, this chapter will focus on the surgery and biomechanics associated with the K1 System of mini-implants.

Rigid Orthodontic Anchorage

Rigid osseous fixation (osseointegration) is a relative term, because even well-integrated endosseous implants demonstrate some flexure relative to supporting bone. For symmetrically threaded titanium implants, the long-term mechanism of rigid osseous fixation is rapid turnover of lamellar bone within 1 mm of the implant surface.⁹⁻¹⁵ In effect, osseointegration is physiologically similar to severe ankylosis.^{11,12} Although bone remodeling (turnover) is very rapid at the bone-implant interface, integrated implants cannot be moved

orthodontically because there is no periodontal ligament.^{11,12} Consistent with a high rate of bone remodeling, up to 40% of the implant surface is adjacent to resorption cavities, and is referred to as remodeling space. Thus, about 60% or more of the surface of the implant is rigidly integrated with bone at any point in time. By definition, osseointegrated implants do not move relative to supporting bone unless the interface is fractured.¹

Rigid implant anchorage has greatly expanded the therapeutic scope of orthodontic mechanics. Many partially edentulous patients with acquired malocclusions can be effectively managed without resorting to extensive extraoral anchorage, orthognathic surgery, and/or extensive prosthetic reconstruction. With implant anchorage, treatment focuses on saving as many teeth as possible and optimal repositioning of the residual dentition for definitive prostheses.

Endosseous implants and subperiosteal onplants are effective anchorages for a broad range of orthodontic applications in both the maxillary and mandibular arches.^{7,16} Clinical techniques, associated with effectively using these devices, are based on the biologic rationale for achieving and maintaining osseointegrated abutments. Implants for orthodontic anchorage and prosthetic support are increasingly important avenues of multidisciplinary interaction for orthodontists, surgeons, and restorative dentists.

Classification of Rigid Implants for Orthodontic Anchorage

Intra-alveolar implants: placed within the alveolar process

- Implant-supported prosthetic abutments
- Small endosseous screws
- Miniature implants

Extra-alveolar implants: placed outside the alveolar process

- Retromolar implants
- Tuberosity implants

- Palatal implants
- Miniature implants

Intra-alveolar Implants

The original use of implants to anchor orthodontic tooth movement was the use of prosthetic abutments to move teeth within the arch or as anchorage for intermaxillary elastics.^{3,17,18} Although the anchorage concepts for prosthetic abutments are usually relatively simple, the diagnosis and treatment planning process to accomplish overall treatment objectives is often quite complex.^{19,20} Many malocclusions requiring implant-supported prostheses and orthodontics are acquired malocclusions with considerable functional compensation. These problems often demand a great deal of tooth movement to achieve esthetic and functional goals in three dimensions.^{11,21-23} Particularly if the intermaxillary relationship changes during treatment, the pretreatment positioning of the implants is problematic. It is usually best to place as few implant-supported prostheses as required to stabilize the desired intermaxillary relationship (Figures 16-1 through 16-3). After orthodontics is completed, placement of additional implants and prosthetic reconstruction of the occlusion is quite predictable. In brief, the major problem

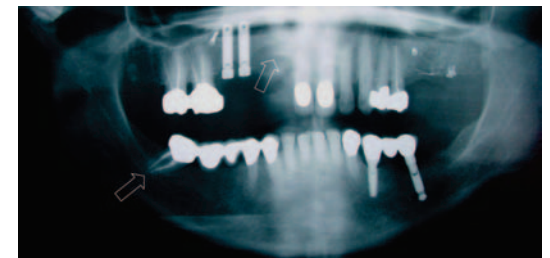


FIGURE 16-1 Case 1. Pretreatment radiograph of a 56-year-old postmenopausal female presenting with a failing distal abutment in the right mandibular segment (*small arrow*) and large surgical defect distal to the right maxillary central incisor (*large arrow*).

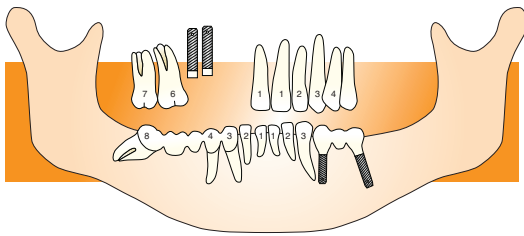


FIGURE 16-2 Case 1. A tracing of the panoramic radiograph is used as a basis for designing the treatment plan.

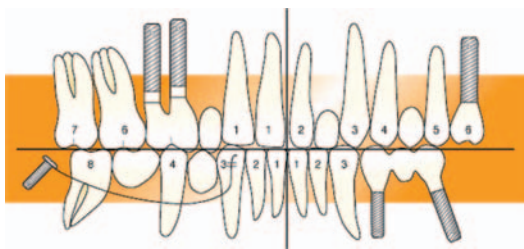


FIGURE 16-3 Case 1. A visual treatment objective is drawn to demonstrate the proposed treatment, using implant anchorage in all four quadrants.

in using implant-supported prostheses for orthodontic anchorage is appropriate treatment planning relative to the stomatognathic response to treatment.²¹ Retromolar implants have proven to be reliable devices for managing severe partially edentulous malocclusions.

Miniscrews

Placement of miniscrews or microscrews in the alveolar process is an increasingly popular intra-alveolar procedure, particularly in Asia.^{8,10,24-28} Placement of these devices is a relatively minor surgical procedure compared with palatal or retromolar implants. The most popular locations are on the labial surface of the alveolar process in both arches, superior to the roots of the maxillary incisors, or in the palate. The sites selected are usually between the roots of teeth or apical to them. A number of the specifically designed products, which are used in Europe and Asia, are not available in the United States, because the clinical use of unique devices requires pre-market approval by the Food and Drug Administration. The miniscrews most commonly used in the United States are the anchor screws, supplied with surgical fixation plates. In general, these screws engage the cortical plate of the alveolus and there is no attempt to achieve osseointegration. In effect, they are temporary bone anchors screwed into an intraoral cortical plate. In addition, osseous fixation pins have been used that extend through the alveolus to achieve bicortical support. Although neither bone-plate screws nor

osseous fixation pins are specifically approved as orthodontic anchorage devices, both products are on the market and have been used for orthodontic purposes. The effectiveness of an off-market use of a surgical screw in the United States was reported by Creekmore and Eklund.²⁹

Cortical plate miniscrews are relatively simple devices that may be effective for limited anchorage demands. However, experience with these devices in animals and patients has demonstrated that there can be a number of problems: (1) soft tissue irritation, particularly if placed in bone covered with alveolar mucosa rather than attached gingival; (2) relatively high rate of loosening (up to 50%) within 6 months; (3) devitalization of teeth adjacent to the surgical site; (4) inability of nonintegrated screws to resist torsion, which limits the anchorage potential for complex force systems; (5) periimplant infection; (6) inhibition of tooth movement in the area where the implants are placed; (7) anatomic limitations on the location of the miniscrews; (8) inappropriate lines of force; and (9) difficulty in controlling the three-dimensional movement of teeth with devices that are designed to anchor only linear forces. In effect, the principal mechanical deficiency of miniscrews is that it is difficult to deliver an appropriate moment-to-force ratio to translate teeth. Although miniscrew anchorage can be effective in select cases, the limitations of the devices may compromise tooth movement and complicate the achievement of desired outcomes.

Despite the anatomic restrictions on the use of intra-alveolar devices, development of a mini-implant that achieves osseointegration has appeal for eliminating many of the problems associated with nonintegrated devices. Following an extensive experience with nonintegrated miniscrews, Kanomi designed a two-stage miniature intra-alveolar implant that routinely achieves osseointegration.⁸ Two studies in dogs demonstrated the clinical use of these anchorage devices.^{10,24} Clinical trial of the K1 System using osseointegrated mini-implants has been promising. Developmental considerations, surgical technique, common problems, and case reports are described later in this article.

Extra-alveolar Implants

Placing osseointegrated implants outside the alveolar processes avoids many of the common problems of intra-alveolar miniscrews, but the process may introduce additional technical procedures and it often requires a more demanding application of biomechanics. Extra-alveolar implants in the palate, tuberosity, or retromolar areas are integrated fixtures that can be loaded in tension, compression, and/or torsion with any moment-to-force ratio desired. They can be used

for direct anchorage, if accessible osseous sites are available intraorally. However, the most effective use of palatal and retromolar implants is often as abutments for indirect anchorage. The fundamental principle is to stabilize teeth that are in desirable positions, for use as anchorage units to move other teeth. In this regard, palatal implants are excellent anchorages for a transpalatal arch to stabilize molars or other teeth in the maxillary arch. Retromolar implants are mandibular devices that use relatively flexible wires, composed of titanium-molybdenum alloy, to anchor cuspids or premolars. The stability of the anchorage teeth or segment is preserved by maintaining the linear orientation of the anchorage wire during space closure (Figures 16-4 and 16-5).

Mini-Implants: K1 System

The K1 System is an osseointegrated miniature implant device specifically designed for orthodontic anchorage. The system consists of small titanium screws for implantation in the jaw bones. There are important considerations when using the system, in terms of diagnosis, treatment planning, orthodontic mechanics, duration of the implantation period, and amount of tooth movement desired. The current use of the K1 System has evolved from a series of developmental studies.

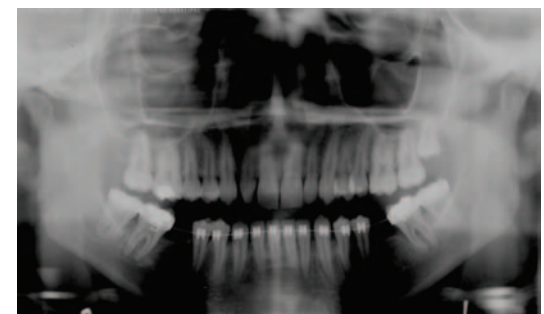


FIGURE 16-4 Case 2. This panoramic radiograph of a 26-year-old female reveals missing first molars bilaterally in the mandibular arch.

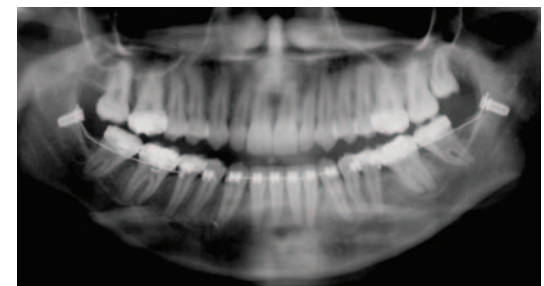


FIGURE 16-5 Case 2. A progress radiograph demonstrates mesial space closure of all four mandibular molars using retromolar implants for anchorage.

Leibinger (Stryker Leibinger GmbH & Co. KG, Freiburg, Germany) microscrews designed for maxillofacial reconstruction were initially used as an anchorage source for orthodontic tooth movement in over 30 clinical cases. Since the microscrews had no hooks, a 4-hole miniplate was cut into two and bent 75° to receive a 0.008 inch ligature wire. However, the plate was sometimes partially buried with bone, making its removal very difficult. To avoid the miniplate problems, a hook was developed that was attached to the implant during a second-stage surgery. This innovation helped to prevent infection and discomfort during the healing stage and greatly facilitated implant removal.

The Leibinger microscrew approach was further modified to produce the current K1 System, which is an orthodontic anchorage device specifically designed for controlling tooth movement while limiting soft tissue irritation. The K1 System has the following features:

- The endosseous base was redesigned as small and simple as possible.
- The size of the implant head was minimized to prevent inflammation.
- Two different diameters were made available (1.0 and 1.2 mm).
- Three lengths (4, 6, or 8 mm) were designed for each diameter (Figure 16-6).
- A hand driver is used to screw the implant body into the bone.
- Mucosal punch facilitates second-stage, soft tissue surgery.
- Specially designed pliers are used to attach a hook to the implant head upon its exposure in second-stage surgery.
- A depth gauge is used to check the dimensions of a drilled hole.
- A rescue implant, 1.4 mm in diameter, is available for use when the hole drilled in the bone is too large.
- All the surgical instruments are organized into a kit that can be sterilized (Figure 16-7).

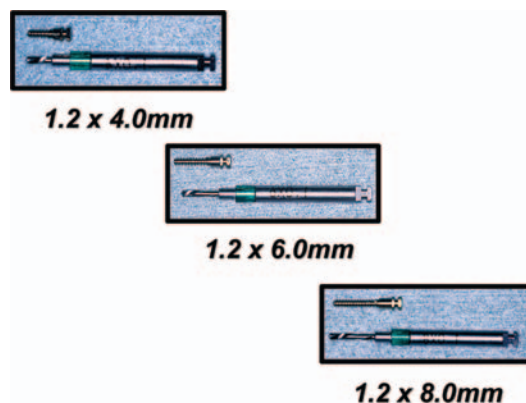


FIGURE 16-6 Pilot drills and mini-implants for 1.2 mm anchorage screws in 4, 6, and 8 mm lengths.

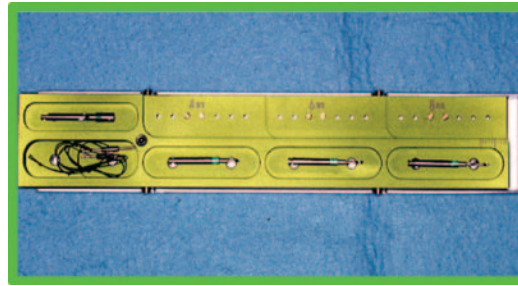


FIGURE 16-7 Surgical kit for the K1 System of mini-implant anchorages.

Surgical Considerations

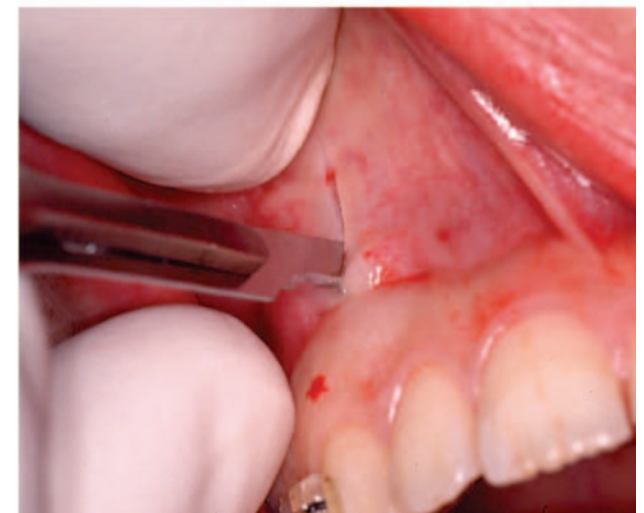
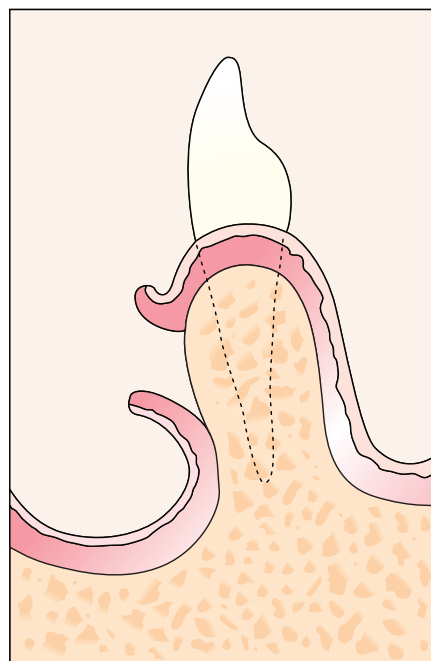
For labial implant placement, a surgical stent is prepared (Figure 16-8). Following the incision of the mucosa, a mucoperiosteal flap is raised to expose the bone surface (Figure 16-9).



FIGURE 16-8 A maxillary dental cast, with maximum labial extension, is used for fabrication of a surgical stent to place the implants superior to the central incisors.



FIGURE 16-9 A surgical incision and reflection is demonstrated for placing a mini-implant.



Then, the bone is scored to mark a starting point for drill penetration (Figure 16-10). Each implant site is prepared with a drill of appropriate length and checked with the depth gauge; then, the implant is inserted with the hand driver. Figure 16-11 shows the K1 screw completely embedded in the bone. The flap is replaced over the endosseous implant and remains covered by the mucosa for a healing period of approximately 3 months. Prior to second-stage surgery, orthodontic leveling and aligning are initiated. After the healing

period, the implant is uncovered and an abutment hook is slipped onto the screw head with specially designed pliers (Figures 16-12 and 16-13). A 0.008 inch stainless steel ligature wire is then tied from the implant abutment to a hook soldered onto an arch wire (see Figure 16-13).

Titanium Mini-Implants for Orthodontic Anchorage.

These purpose-designed devices provide rigid anchorage and can be used for various types

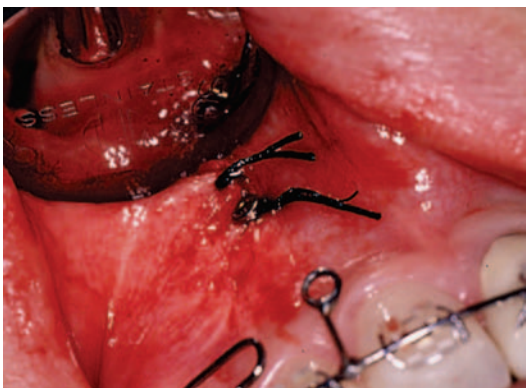


FIGURE 16-12 Postoperative view of the implant following wound closure.

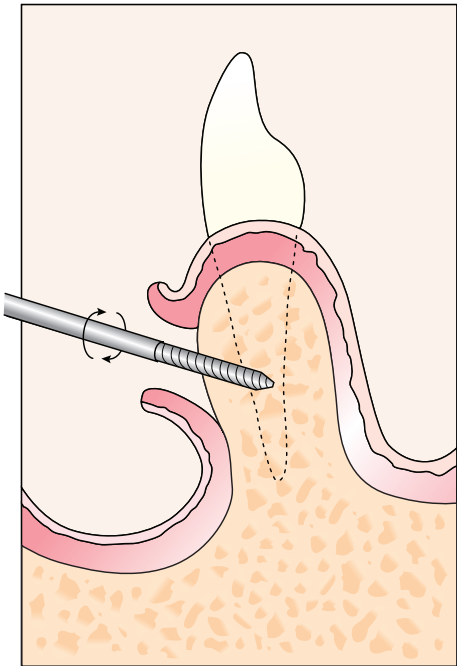


FIGURE 16-10 The hole is prepared with the pilot drill at the position determined with the surgical stent.

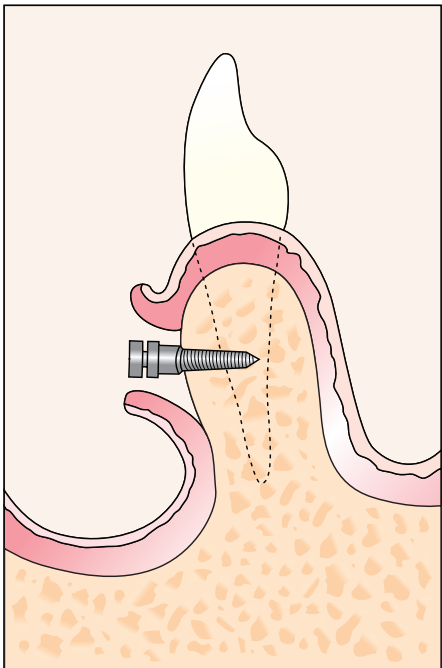
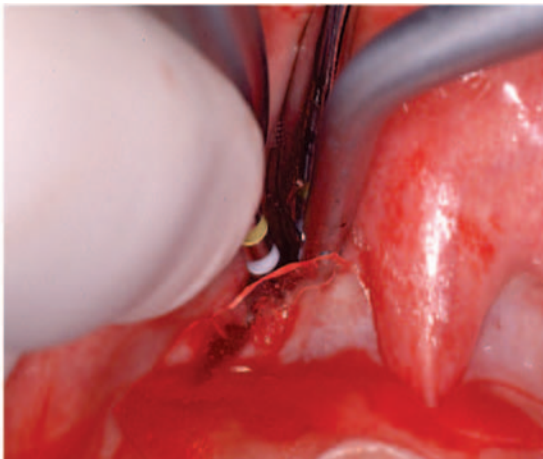


FIGURE 16-11 The mini-implant is placed and the soft tissue is sutured around it.



FIGURE 16-13 After a healing interval of 3 to 4 months, the abutment hook is slipped over the implant head with specially designed pliers.



of tooth movement. Implant orthodontics with the K1 System requires adequate bone and interradicular space for safe drilling of the 1.2 mm diameter holes, into which the screws are inserted. The most commonly used implants are 4 and 6 mm in length, but even the 8 mm long implants can be placed if an adequate amount of cortical bone is available. Indications for implant anchorage include canine retraction, intrusion of incisors, intrusion of molars, and retraction of buccal segments. To intrude maxillary incisors, K1 screws are placed in the lower border of the anterior nasal spine; intrusive force is delivered with a ligature wire tied from the implants to the arch wire, as schematically depicted in Figure 16-14.

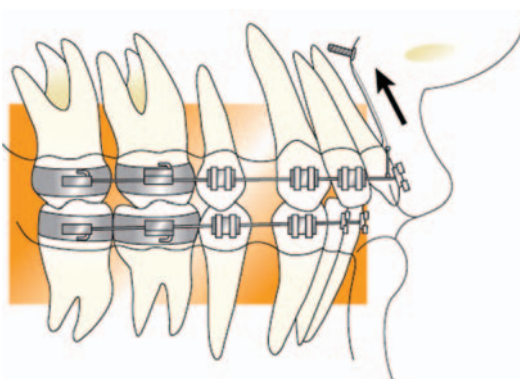
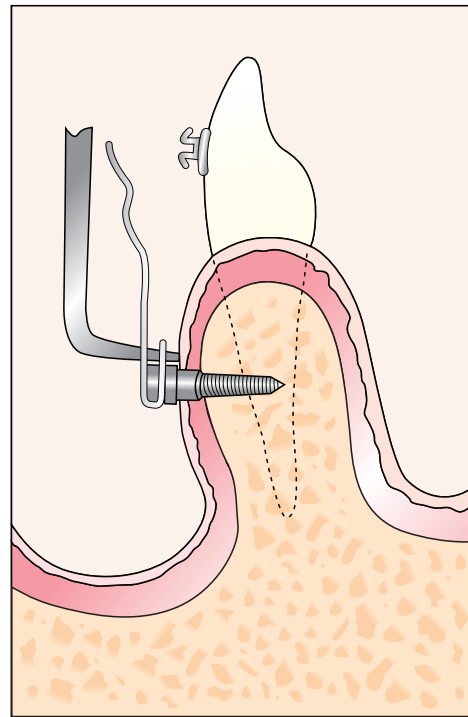


FIGURE 16-14 This schematic drawing shows the use of the mini-implants for anchorage to intrude maxillary incisors.



Computed Tomography Imaging

Computed tomography (CT) imaging helps determine where to place implants (Figures 16-15 and 16-16). CT scans are helpful for all potential implant sites, but are critical when implants are placed outside the arches in the thin cortical plate

of the maxilla. Implants placed in the superior and posterior aspects of the maxilla may perforate into the sinus. The CT scans are critical for determining areas where the bone is too thin to safely serve as an implant site. Penetration of the maxillary sinus must be avoided, particularly in the presence of sinus inflammation.

Implant Failure

Potential causes of implant failure include drill-implant mismatch, external contact pressure from the tongue or buccal mucosa, infection, and poor bone architecture. Root resorption and implant stability should be regularly monitored with radiographs during the intrusion phase. Care must be taken to avoid overloading of the anchorage implants, because they have a relatively small surface area that is integrated with bone.

Case Report

A 15-year-old female was presented by her mother for orthodontic consultation (Figure 16-17). The chief complaint was a “gummy smile.” Examination revealed a Class II division 1 malocclusion with a 4 mm overjet and a relatively short upper lip. Despite the opinion of her mother, the patient had a strong personality and initially did not desire treatment. A long consultation was needed to explain the esthetic benefits that could be achieved. Since the patient was not suited to

Cone-beam CT X-ray system for dental and maxillofacial applications

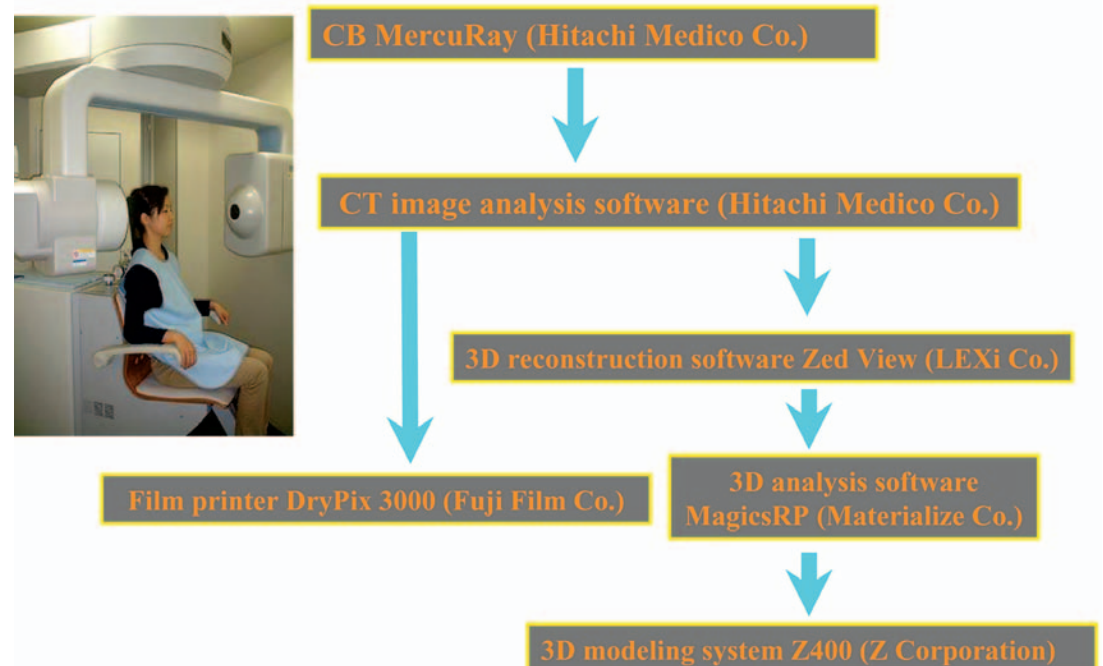


FIGURE 16-15 A computed tomography system, specifically designed for dental imaging, is used in Dr. Kanomi’s office for presurgical and postoperative assessment of implant sites.

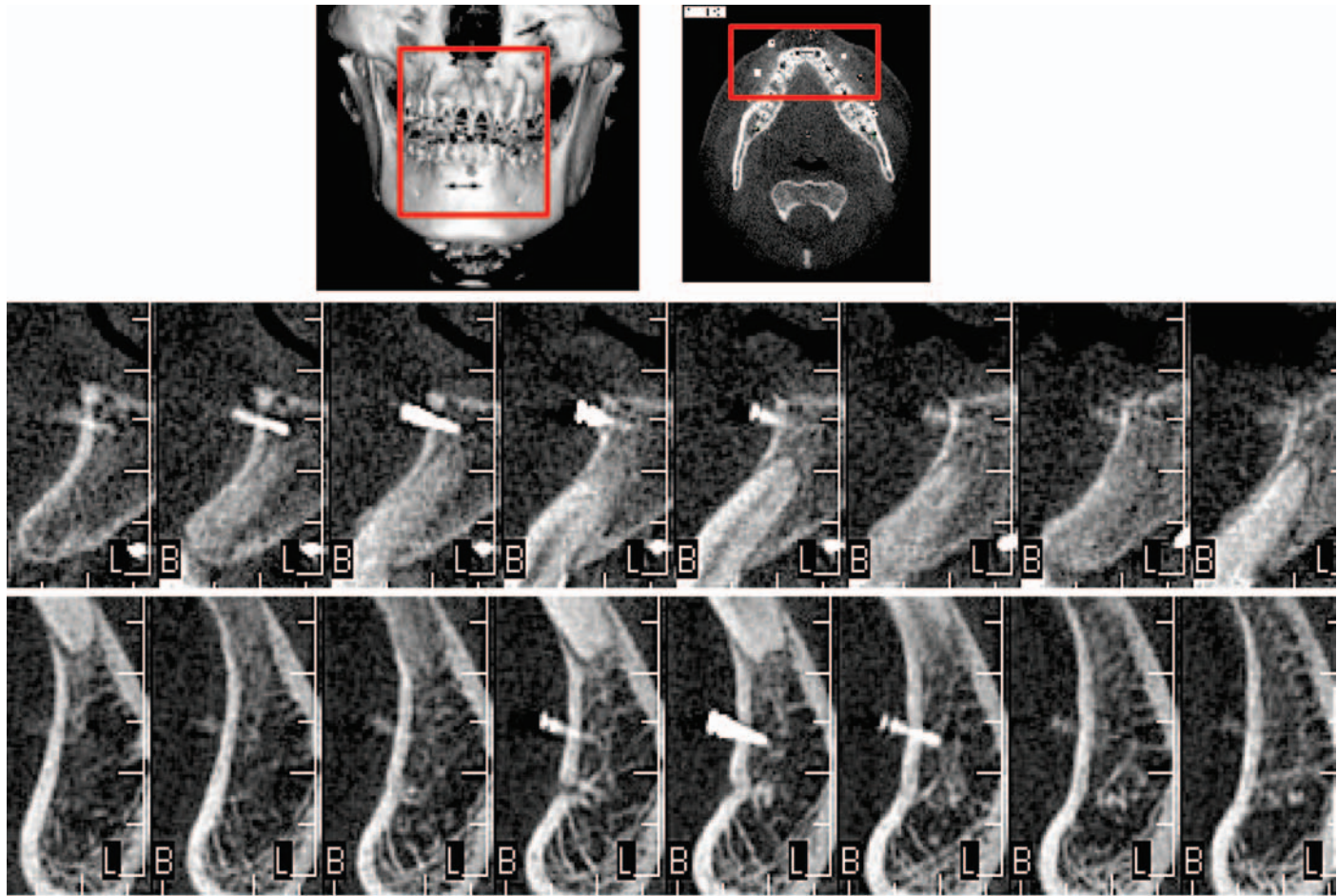


FIGURE 16-16 Computed tomography scans are used to evaluate the postoperative placement of many implants apical to the maxillary and mandibular incisors.



FIGURE 16-17 Case 3. A 15-year-old female presents with a chief complaint of a “gummy smile.”

extensive headgear wear, the most viable options were full arch orthodontic therapy combined with orthognathic surgery or implant-supported anchorage. After thorough consultation and careful consideration, the patient and her mother agreed to full orthodontic treatment using the K1 system for supplemental anchorage. Mounting of the pretreatment casts on an articulator in centric relation revealed a slight Class II occlusal relationship (Figure 16-18). Excessive



FIGURE 16-18 Case 3. The pretreatment photographic series reveals that Class II buccal segments, mild crowding, and a dental bimaxillary protrusion are associated with the excessive gingival exposure.

gingival exposure was noted upon smiling (see Figure 16-17).

Once treatment was initiated, the patient repeatedly asked for early appliance removal, which was seriously considered because she was a poor cooperater with regard to maintaining oral hygiene, complying with treatment recommendations, and keeping appointments. Approximately 6 months after the start of treatment, the patient had an opportunity to go to Australia as an exchange student, and she wanted to have the appliances removed before leaving. From that point on, she was motivated and cooperation improved dramatically.

As previously described, the implants were placed with a surgical stent (see Figure 16-8). The postoperative panoramic radiograph demonstrates the position of the implants relative to the incisor roots (Figure 16-19). Following extraction

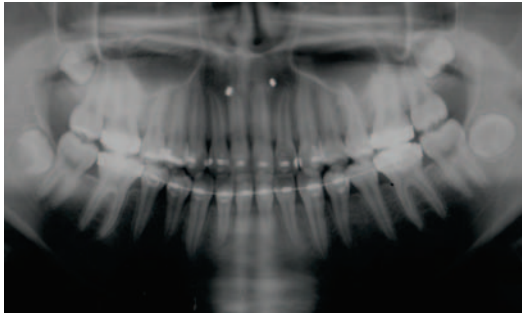


FIGURE 16-19 Case 3. The postoperative panoramic radiograph demonstrates the position of two mini-implants apical to the maxillary central incisors.

of maxillary and mandibular second premolars, the anterior segments were leveled, as the posterior teeth were moved mesially (Figure 16-20). Second-stage surgery was performed to connect abutments to the implants, and intrusive force was applied to the maxillary anterior teeth (Figure 16-21). An adequate amount of intrusion was achieved in approximately 3 months. The remaining spaces in the mandibular arch were closed at the same time.

When correcting a gummy smile in a patient with crowded and/or protrusive incisors, it is more common to extract the first premolars, rather than the second premolars, to avoid excessive deepening of the bite. However, this is of little concern when the maxillary anterior teeth are

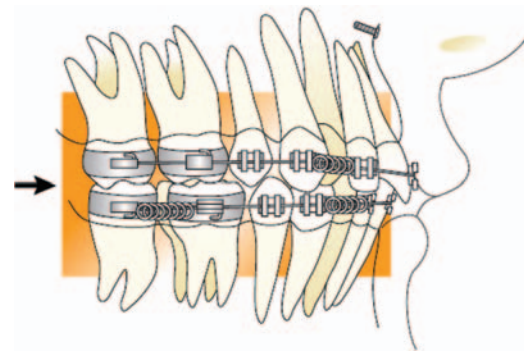


FIGURE 16-20 Case 3. This schematic drawing illustrates the cuspid retraction and mandibular molar protraction prior to initiating maxillary incisor intrusion.

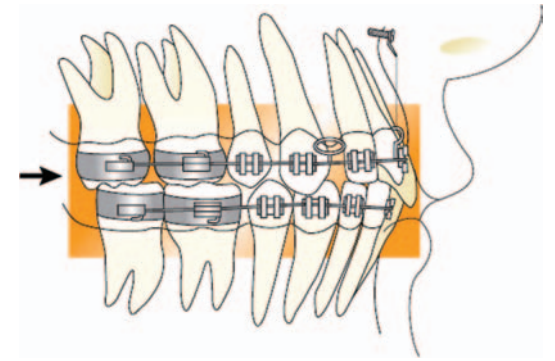


FIGURE 16-21 Case 3. This schematic drawing demonstrates the mechanics to intrude the maxillary incisors.

intruded with K1 System. On the contrary, second premolar extraction may be more advantageous, in that the extraction of the mandibular second premolars causes the anterior bite to deepen, which in turn increases the amount of maxillary anterior intrusion that is possible. This results in a greater improvement of the gummy smile. Figure 16-22 shows the occlusion at the end of treatment. The patient's smile was improved significantly with approximately 3 mm of maxillary anterior intrusion. Two years later, the result was stable, as confirmed with superimposition of



FIGURE 16-22 Case 3. The posttreatment photograph series of the patient at 17 years and 1 month of age illustrates the completed treatment.

cephalometric tracings (Figures 16-23 through 16-25). Previously, this type of treatment was possible only with orthognathic surgery. Currently, implant-anchored orthodontics allows for successful yet conservative treatment of these cases. The treatment was finished in 20 months. Anecdotally, after the patient returned from Australia, she reported being “very popular with the boys” and had finally come to appreciate the treatment performed by her orthodontist!

When diagnosis and treatment planning is performed for implant-anchored orthodontics, it is important to mount the casts in the centric relation position and construct a visual treatment objective to clearly define treatment goals. The importance of informed consent cannot be overemphasized. More precise examinations with the CT equipment and wider application of implants to various types of cases will further expand the potential of implant orthodontics with osseointegrated mini-implants (see Figures 16-15 and 16-16).



FIGURE 16-23 Case 3. The maxillary anterior segment was intruded about 3 mm to correct the excessive gingival exposure when smiling.



FIGURE 16-24 Case 3. The intraoral photographic series of the patient at 18 years and 9 months of age (~2 years after treatment) demonstrates excellent stability of the result.

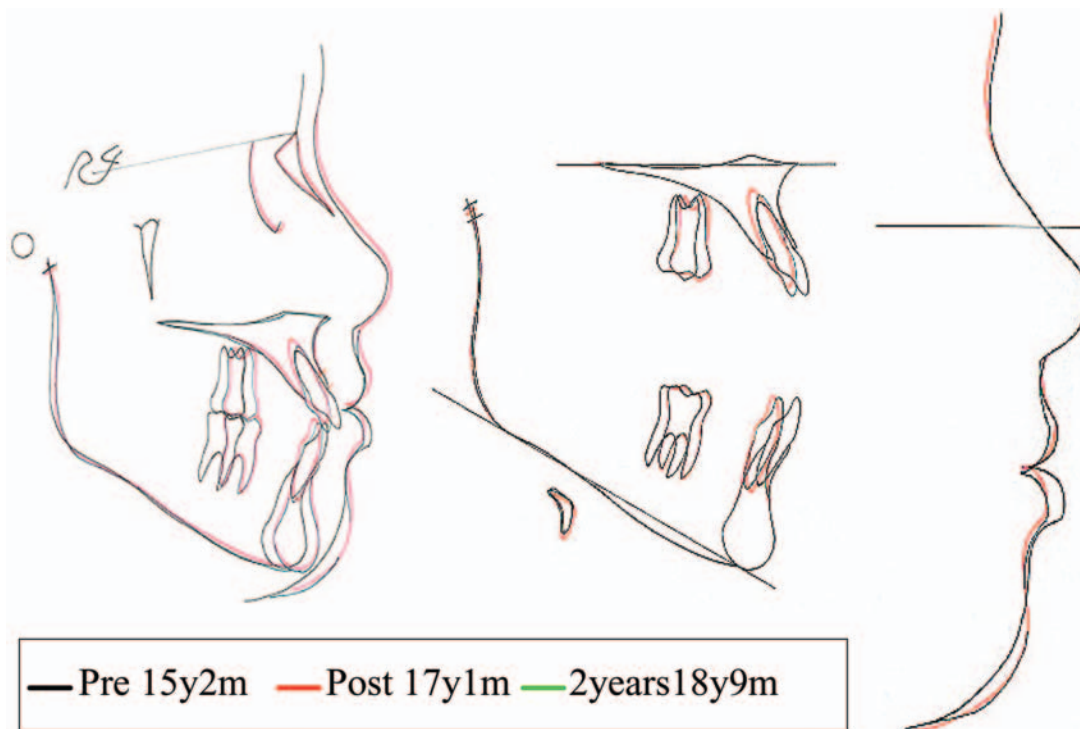


FIGURE 16-25 Case 3. Superimposition on the anterior cranial base, maxilla, mandible, and Frankfurt horizontal illustrates the cephalometric changes pretreatment (15-years 2-months old), posttreatment (17-years 1-month old), and during follow-up (18 years 9-months old).

Conclusion

Retromolar implants continue to be the anchorage mechanism of choice for intrusion and mesial translation of mandibular molars. They have also proven useful for aligning excessively tipped prosthetic abutments. Palatal implants are a well-established means of controlling maxillary molar anchorage. This article introduces an osseointegrated mini-implant system that is suitable for intrusion of incisors and other limited intra-arch anchorage needs. CT scans are rarely indicated for placement of retromolar or palatal implants because of an abundance of bone at the surgical site. However, miniscrews and mini-implants are often placed in thin bone that approximates the nasal cavity, maxillary sinus, or roots of teeth. CT scans are very helpful for precise positioning of small implants in thin cortical plates.

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Open-Bite Closure by Intruding Maxillary Molars with Skeletal Anchorage

Laszlo Seres and Andras Kocsis

In young patients, vertical maxillary growth can be controlled with a high-pull headgear or a functional appliance with bite blocks (Figure 17-1). Once excessive vertical development of the posterior maxilla has occurred, there are only a few treatment options for the correction of an open bite. Elongation of the anterior teeth leaves the skeletal component of the deformity unchanged. Intrusion of the overerupted molar teeth with traditional orthodontic methods is questionable; therefore, there is no real alternative for a combined orthodontic and surgical approach.

The most frequently performed surgical procedures for anterior open-bite correction are superior repositioning of the maxilla via Le Fort I osteotomy, posterior maxillary osteotomy, and vertical ramus osteotomy.

Fear of surgery or general anesthesia and other factors may lead a significant proportion of patients to refuse surgery. Bailey and colleagues reported that fewer than half of the patients who seek orthodontic treatment for long-face problems do not accept the recommended orthognathic surgery.¹ Proffit and colleagues suggested that a patient with a skeletal long-face

problem who refuses surgical correction is better left untreated.² Patients may prefer a less invasive surgical procedure with little risk and morbidity. A gradual change in the facial appearance may be more acceptable for some patients than an immediate change. Ambulatory surgery done with anesthesia rather than general anesthesia significantly reduces the cost and time of treatment.

When the surgical intrusion of maxillary teeth is performed, the mandible rotates closed at rest and in function.³ Until recently, there was no orthodontic approach that would predictably intrude molar teeth in nongrowing patients. Titanium miniplates implanted in the zygomatic buttress area were recently introduced as absolute anchorage for maxillary molar intrusion (Figure 17-2).⁴⁻⁶

Indications

The main indication for maxillary molar intrusion by skeletal anchorage is an anterior open bite owing to posterior maxillary vertical dentoalveolar hyperplasia. This treatment can be useful for managing relapse after standard orthognathic surgery, that is, mandibular advancement. When an open bite is associated with transverse maxillary deficiency, three-piece segmental maxillary surgery may be avoided. In some patients, especially Class III cases, the optimal skeletal relationship cannot be achieved through the intrusion of upper molars alone; instead, treatment by one jaw surgery alone may be possible.

Further indications are the overeruption of maxillary molars resulting from the loss of opposing occluding teeth and unilateral or bilateral mandibular hypo- or hyperplasia associated with elongation of the maxillary dentoalveolar process. In cases of traumatic maxillary rotation (when orthognathic surgery is usually required for correction, but orthodontic compensation may

be acceptable), skeletal anchorage should be considered part of the treatment plan. Mandibular asymmetry is often accompanied by maxillary compensation, which is reflected clinically by a transverse cant of the maxilla. In such cases,



FIGURE 17-1 An open bite is usually one of the main symptoms of an overall dentofacial deformity. Most anterior open-bite cases are characterized by the overeruption of maxillary molars.

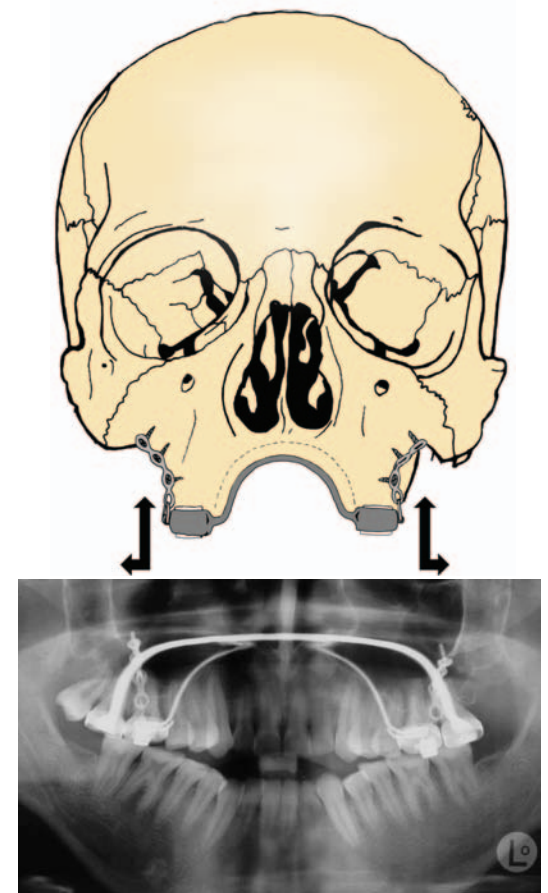


FIGURE 17-2 Before the implantation of the skeletal anchors, the molars are separated and the molar bands are adapted. The intrusion of the molars by a force directed only apically to the buccal tooth attachment would result in adverse buccal tipping. To avoid this, the molars are connected with two transpalatal arches.

the unilateral vertical maxillary excess can be corrected by intrusion of the elongated dentoalveolar segment.

Sequence of Treatment Planning

- 1. Dental and periodontal treatment
- 2. Banding of the molars and adaptation of the transpalatal arch (TPA) or Hyrax appliance to control maxillary expansion
- 3. Placement of skeletal anchorage and surgical removal of impacted molars and premolars (if necessary)
- 4. Fixed edgewise appliance therapy
- 5. Application of the intrusive force
- 6. Termination of the intrusion; retention of the intrusion
- 7. Removal of the miniplates
- 8. Removal of the fixed appliance
- 9. Retention

Transpalatal Arch

TPAs have the extra advantage of adding the intermittent intrusive force of the tongue onto the molars. TPA adaptation could be performed following surgery, but the manipulation of orthodontic devices around an operation site would cause the patient more discomfort (Figures 17-3 through 17-7).

Surgical Procedure

Both the placement and the removal of the plates are performed on a day-case basis. The procedure can be performed under local anesthesia, with or

without sedation (Figures 17-8 through 14). Removal of impacted third molar teeth that may interfere with the intrusion of the second molar should be performed at the same time (Figure 17-15).

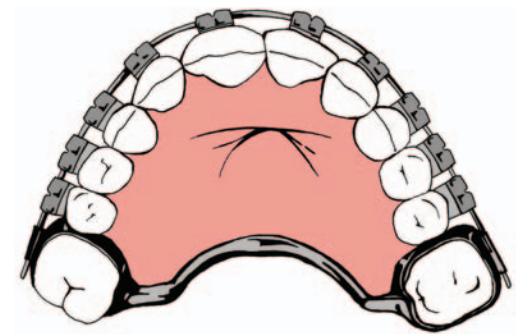


FIGURE 17-4 When only the first or the second molars are intruded, the soldered transpalatal arch is used.

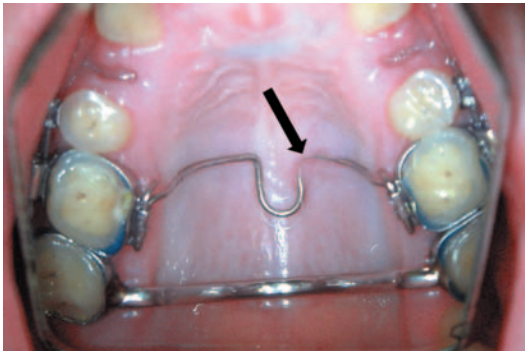


FIGURE 17-5 During the intrusion, the transpalatal arches (TPAs) move upward. Normally, the TPA lies 2 to 3 mm away from the palatal mucosa, but in the event of intrusion, this would result in impingement of the soft tissues.

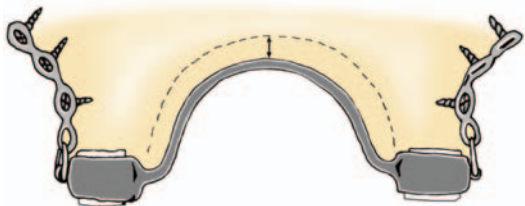


FIGURE 17-6 To avoid soft tissue impingement, the distance of the planned intrusion must be added to the normal transpalatal arch (TPA) to palate distance. If a 3 mm intrusion of the molars is planned, the TPA to palate distance should be at least 5 to 6 mm.

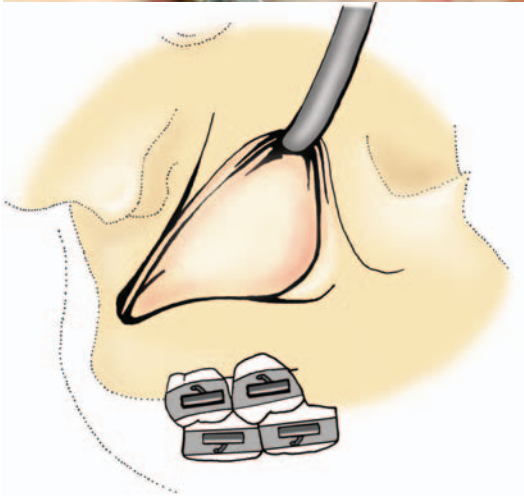
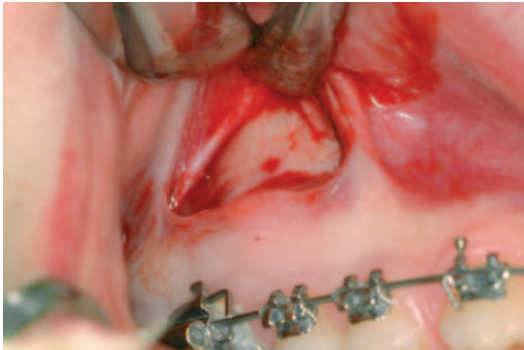


FIGURE 17-8 With a periosteal elevator, a full-thickness mucoperiosteal flap is reflected superiorly to expose the zygomatic process of the maxilla. The mucoperiosteum inferior to the incision is left attached to the bone.

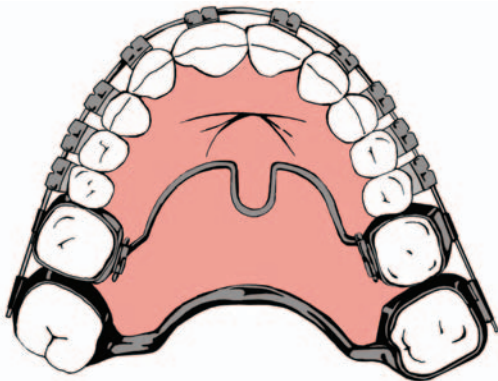


FIGURE 17-3 A Goshgarian-type transpalatal bar is bent from a 0.036-inch (0.9 mm) stainless steel wire so as to extend from the maxillary first molar, along the contour of the palate, to the maxillary first molar on the opposite side. Another 5 × 1 mm prefabricated cobalt-chrome-alloy transpalatal arch (TPA) is soldered to the palatal aspects of the second molar bands. The soldered TPA prevents torque and tipping of the molars until the mesiodistal and orovestibular angulation can be corrected with the Goshgarian-type TPA during treatment.



FIGURE 17-7 Following infiltration of a local anesthetic with a vasoconstrictor at the height of the maxillary vestibule, a 2 cm horizontal mucoperiosteal incision is made, extending from the second premolar to the second molar over the attached gingiva. No local anesthetic is injected into the palate.

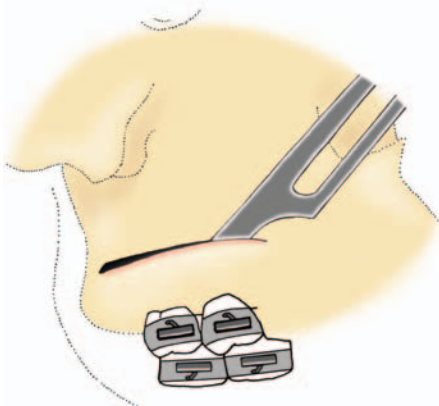




FIGURE 17-9 A 4-hole I-shaped miniplate (Synthes, Oberdorf, Switzerland) is adjusted to fit the contour of the zygomatic process. A and B show the course of the zygomaticoalveolar crest and the position of the molar teeth in the arch are variable, C shows the dense cortical bone of the zygomatic buttress area gives flexibility in plate positioning.

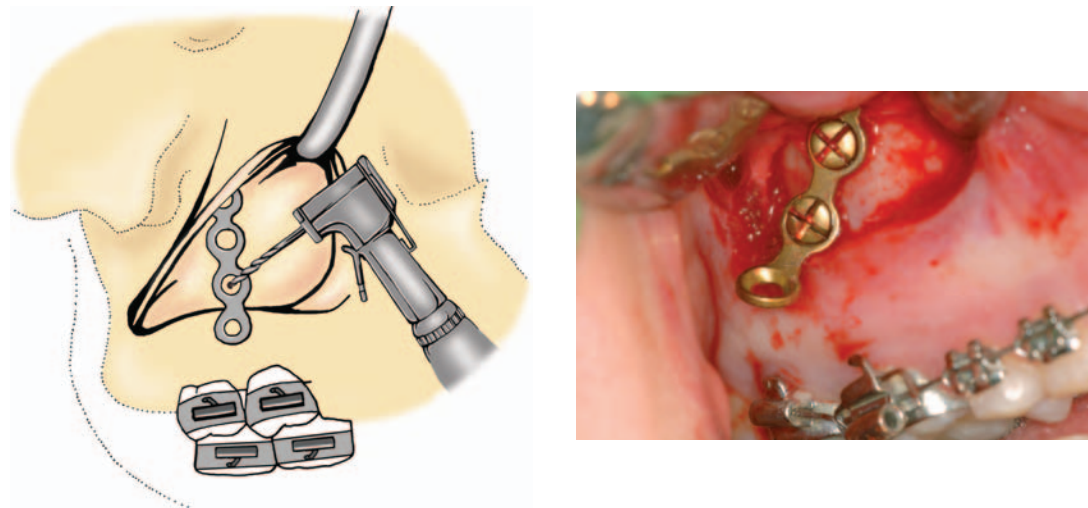


FIGURE 17-10 A drill with a 4 mm–depth stop is used and the plate is fixed by three 4 mm screws. L-, T-, or Y-shaped plates can also be used. The proximal edge of the plate should be at least 1 cm from the molar tube. This will ensure that the screws are inserted well above the root tips so as to avoid root damage during drilling or interference with the intrusion.

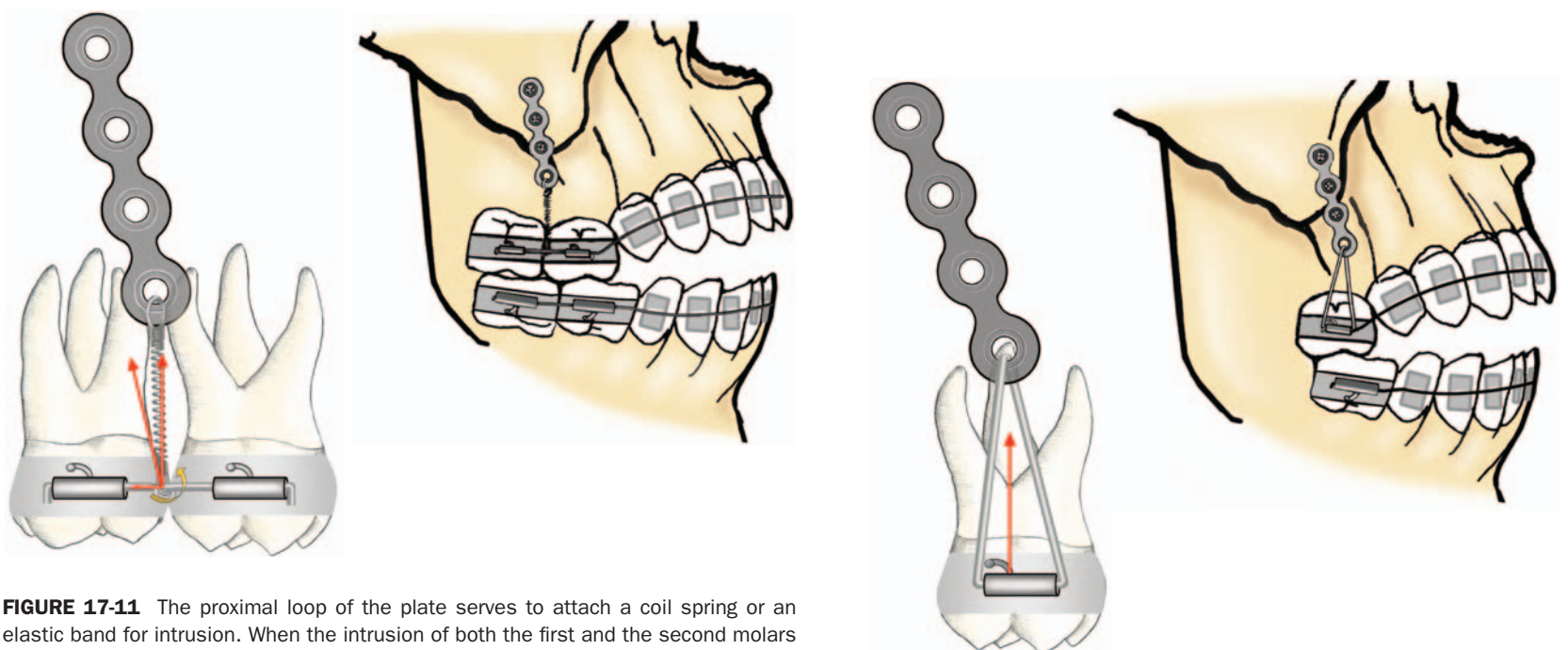


FIGURE 17-11 The proximal loop of the plate serves to attach a coil spring or an elastic band for intrusion. When the intrusion of both the first and the second molars is planned, the ideal position of the most proximal loop of the plate is between the roots of the teeth to prevent unfavorable mesiodistal angulation during the intrusion. This figure shows the scheme of intrusion force vectors and couple-force ratio.

FIGURE 17-12 When only one molar is to be intruded, the last loop should be placed over the vertical axis of the tooth.



FIGURE 17-13 The mucoperiosteal flap is repositioned and the surgical wound is sutured, with the last hole of the anchor plate exposed intraorally.

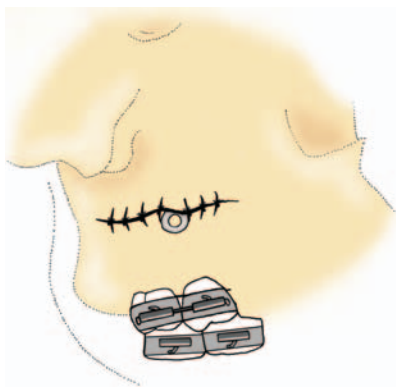


FIGURE 17-14 A posteroanterior cephalometric radiograph is taken to assess the position of the miniplates after the implantation.

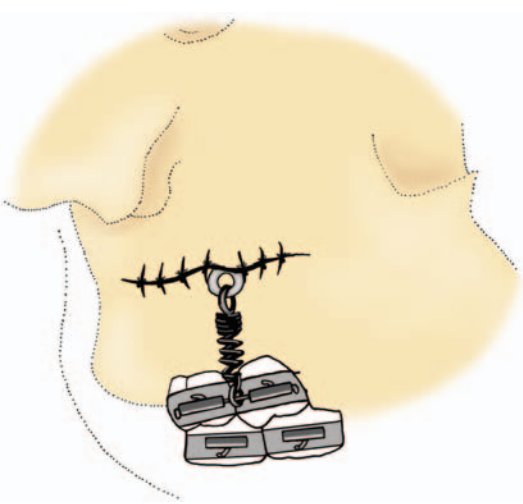


FIGURE 17-15 To provide continuous light forces of 100 to 120 g, 9 mm nickel-titanium closed coil springs (0.010 inch) or elastic rings are placed bilaterally between the exposed hole of the miniplate and a hook on the segmental wire between the molar buccal tubes. When only one molar tooth is intruded, the spring or the elastic band is attached to the molar tube.

Orthodontics

Orthodontic force can be applied immediately following the implantation. Frequently, however, we allow 1 to 2 weeks for soft tissue healing with a view to minimizing patient discomfort Figure 17-16).

After the intrusion force has been delivered, the patient is seen at 3-week intervals. The following examinations and measurements are made and monitored:

1. The mobility of the molars
2. The distance of the TPAs from the palatal soft tissues
3. Unfavorable mesiodistal or orovestibular angulation

4. Intrusion: the distance between the edge of the miniplate and the molar tubes
5. Open-bite closure: the vertical distance between the edges of the central incisors.

In selective cases, transverse deficiency may be concomitantly corrected by the TPA or Hyrax appliance.

Three months after the application of the intrusive force, standardized periapical radiographs or three-dimensional cone-beam computed tomographic (CBCT) scans are taken to evaluate the change in the marginal bone level and the amount of root resorption. The intrusion is terminated when the open bite has been visually corrected.

Posteroanterior and lateral cephalometric radiographs (Figure 17-17), an orthopantomogram, and periapical radiographs are taken to assess the postintrusion status. The three-dimensional CBCT scan is preferable when available.

Following this, traditional fixed bracket therapy is completed.

Oral Hygiene and Periodontology

The patient is instructed on how to brush around the anchor site and to rinse with 0.2% aqueous chlorhexidine twice a day after surgery and throughout the orthodontic treatment. Every time a patient visits the orthodontic clinic during the intrusion, a periodontology appointment is given for professional cleansing. The clinical records taken by the periodontologist include probing depths, mobility, gingival recession, and bone levels.

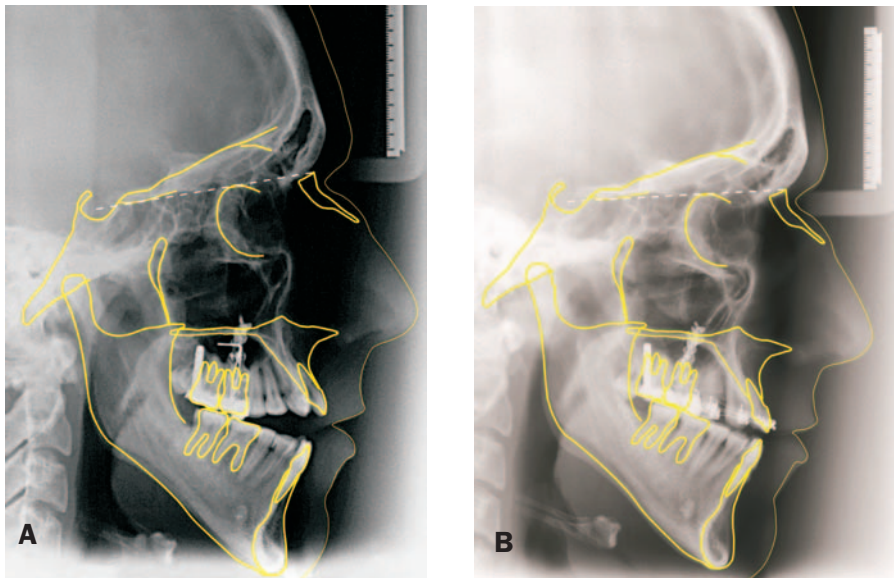


FIGURE 17-16 A, Initial cephalometric radiograph. B, Progress cephalometric radiograph.



FIGURE 17-17 The molars are stabilized with vertical wire ligations between the molar tubes and the miniplates.

Complications

Complications with plate placement or removal are extremely rare. Miniplates fixed with short screws in the zygomatic buttress area involve little or no risk of damaging dental roots. Mild postsurgery pain and facial edema are often present, but these usually subside rapidly.

Periapical changes and periodontal tissue alterations are followed by bone remodeling around the intruded molar roots.

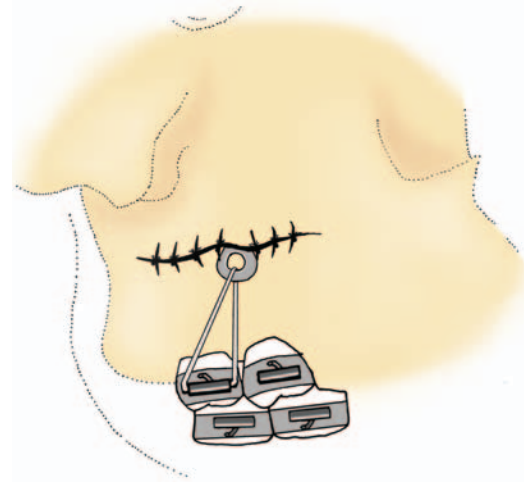
Post-Treatment Stability

Stability is one of the most important issues after a dentofacial deformity correction. As maxillary molar intrusion for an open-bite closure with a skeletal anchorage is a new treatment approach, long-term results have yet to be published.

Both long-term follow-ups of ongoing treatments and future studies will furnish more information on relapse rates. If, according to the equilibrium theory, the forces of occlusion prevent the reeruption of molars and thus the relapse of an open bite, no special retaining methods may be necessary.

Conclusion

Skeletal anterior open bites owing to posterior maxillary dentoalveolar hyperplasia can be closed without orthognathic surgery (Figure 17-18). Titanium miniplates are recommended for temporary skeletal anchorage. The dense cortical bone of the zygomatic buttress area is an ideal miniplate anchorage site for maxillary molar intrusion (See Chapter 13, “Speedy Surgical Orthodontic Therapy with Dentoalveolar Distraction Osteogenesis”). Both placement and removal of



the plates are minimally invasive procedures with only slight discomfort to the patient and no serious side effects. The treatment can be done in an ambulatory setting. Collaboration of orthodontists and maxillofacial surgeons is essential.

This method is a safe, quick, and less expensive alternative to orthognathic surgery. More structured research projects with a greater number of patients and long-term follow-ups are necessary to establish precise indications, surgical and orthodontic techniques, and procedures.

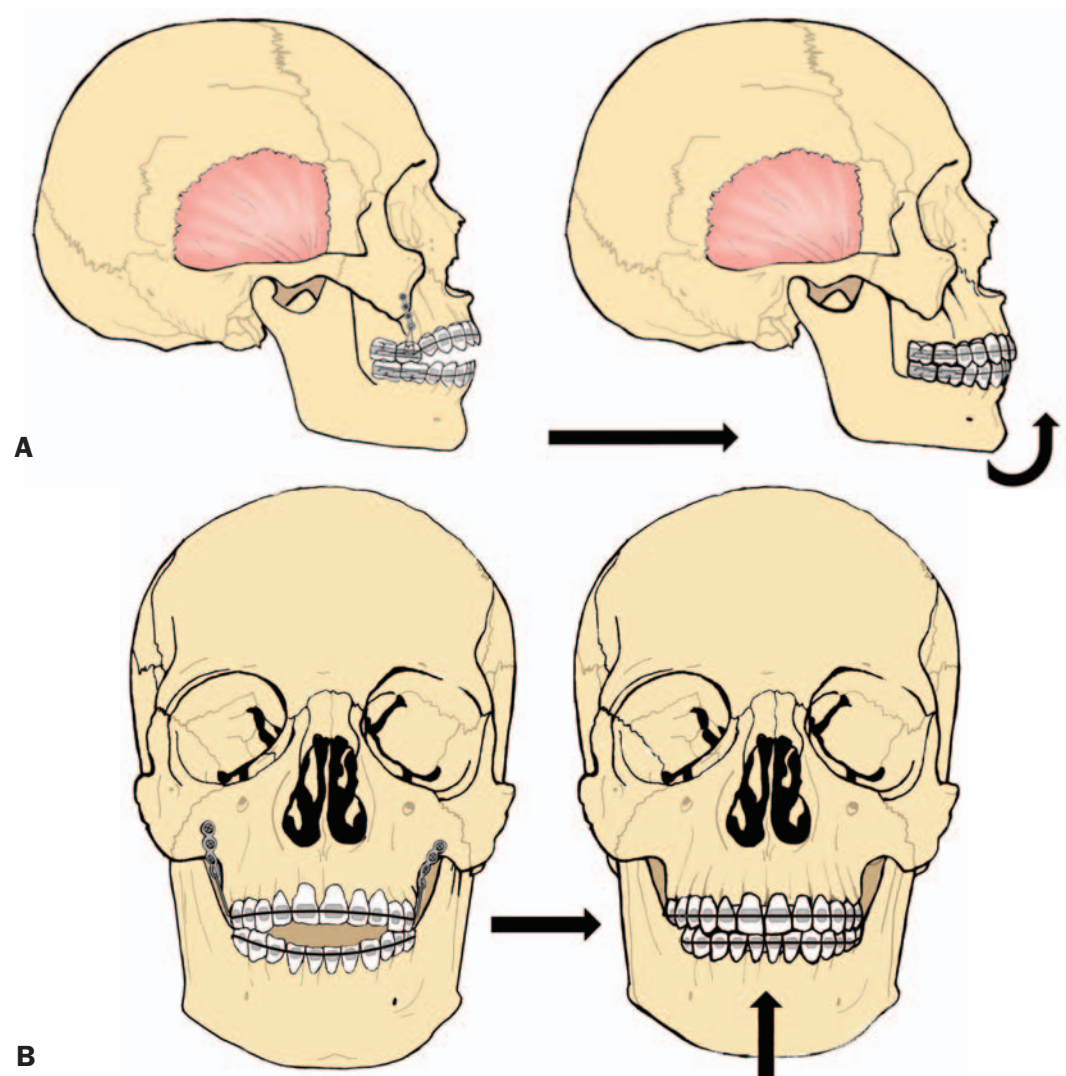


FIGURE 17-18 A and B, Orthodontic intrusion of maxillary molars results in open bite closure.

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Maxillary Lengthening by Orthognathic Surgery

David S. Precious

As early as 1907, Blair wrote, “Once destroy that nice balance upon which the natural development depends and the normal muscular forces will operate to exaggerate the malrelation.”¹ It is now known that in many cases of jaw deformity, it is in fact abnormal and dyssymmetric muscle forces that cause and exaggerate the problem. Improvement in the results of correction of maxillofacial deformities by orthodontic treatment and orthognathic surgery has been steady, and even dramatic, over the past 30 years. The vast majority of treated cases demonstrate improved occlusion and esthetics, but it must be stressed that unless there is symmetry and balance of the relevant muscles, the predictability of long-term changes of bone and soft tissue is variable, irrespective of the method used to move the bones. Furthermore, except in very severe deformities, orthodontic treatment and orthognathic surgery are elective, the fact of which carries with it the necessity to rigorously apply strict parameters of assessment when attempting to establish a risk–benefit ratio.

In the overview, distraction osteogenesis and orthognathic surgery are not mutually exclusive. A point in favor of distraction is not necessarily an argument against orthognathic surgery. More long-term data exist on maxillary advancement with orthognathic surgery, than with distraction, so more is known about orthognathic surgery.² Furthermore, it is generally accepted that the use of distraction to advance the maxilla can be more expensive and certainly more time consuming than orthognathic surgery. What are some of the questions to which we would like to have answers? We would like to know if the results are actually better with one or another technique. What about patient convenience? Is it possible, by use of orthognathic surgery or distraction, to eliminate or make redundant the need for adjunctive surgical procedures? What about the duration of treatment, which is something quite distinct from patient convenience? What are the costs of orthognathic surgery versus distraction osteogenesis? How frequent is the need for

further surgery at the end of growth? Unfortunately, definitive answers to these difficult questions remain somewhat unclear.

Clinical Foundation and Indications

In assessing facial balance, the surgeon must consider that there are three types of maxillary movements that are responsible for its growth. Posteroanterior translation of the maxilla takes place in the newborn and in the young child, until about 4 years of age, under the influence of the actively growing brain, nasal capsule, and nasal septum. After this age, the maxilla, which is attached to the external cortex of the frontal bone, is affected by the formation and growth of the frontal sinus, continued growth of the nasal septum, and ambient functional influences of the facial muscles.

Anterior rotation of the maxilla is active for about the first 1.5 years of life, and then again at puberty. It is accompanied by an upward movement of the nasal bones and ascension of the nose, and it is this movement that is impossible to observe when the Sella Nasion angle (SNA) is used alone to measure the forward position of the maxilla. Maxillary rotation is important in establishing either normal or pathologic facial balance.

Vertical elongation of the maxilla and descent of the palate take place at about the same time as translation, and are influenced by active growth of the brain and ocular contents, as well as from below by their various muscular connections with the mandible, soft palate, and tongue. The nasal septum also plays both a direct and indirect role in lowering and advancing the position of the anterior nasal spine.

Distraction osteogenesis may be particularly useful to elongate the maxilla in severe cases and in those resulting from cleft lip and palate. Although we can celebrate that there is a new technology to correct this difficult clinical problem, we should not overlook the fact that inadequate or inaccurate primary surgery is

usually the reason why very large advancements of the midface in patients with cleft lip and palate are required at all.

Orthognathic surgery is accurate. There are accurate methods of diagnosis, relatively accurate methods of treatment prediction, and good and accurate methods for outcomes assessment, at least with respect to the stability of the bones that have been moved. In my opinion, orthognathic surgery is very frequently and too narrowly thought of in terms of osteotomies. This perception probably arises because orthognathic surgery is unsurpassed in its applicability to correction of certain dentofacial deformities (Figure 18-1).

Orthognathic surgery, however, is much broader than just osteotomies; it is a constellation of procedures that permit differential alteration and repositioning of bone, cartilage, muscle, teeth, gingiva, mucosa, and skin. Distraction osteogenesis involves the lengthening and reshaping of bones by surgical fracture and gradual separation of the bony segments. The contiguous tissues are *concomitantly* stretched.

Development of the midface is both hierarchical and integrated. The development of muscles precedes that of bones. The bones of the midface develop under the influence and at the direction of the enveloping muscles. In other words, there is a set of circumstances where muscles are shaping bones. In distraction osteogenesis, the roles are reversed because the elongating bone is driving its attached muscles.

A good example of muscles controlling bones is that which happens in utero with cleft lip and palate (Figure 18-2). The distortion of the bones is already present when the baby is born. This is muscle distortion of bone, and in the case of cleft lip and palate, all of the nose muscles, cheek muscles, and lip muscles, acting through the breach, combine to distort the face. Early orthognathic surgery is muscle surgery. Early orthognathic surgery seeks to achieve differential alteration in the repositioning of, in this case, cartilage, muscle, mucosa, gingiva, and skin. Once this has been accomplished, the bones will follow.

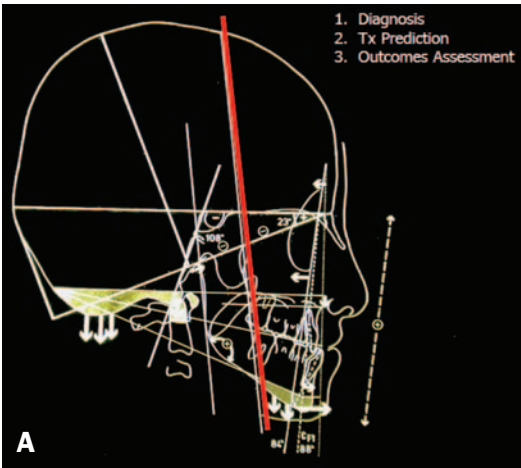


FIGURE 18-1 A, Graphic Delaire Analysis used for diagnosis, prediction tracing, and outcomes assessment of skeletal and soft tissue movements. B, Correction of vertical maxillary excess using traditional orthognathic surgery.

In early orthognathic surgery, the muscles are the distractors, as demonstrated in Figures 18-3 and 18-4, showing the 7-day postsurgical repair of cleft lip and palate, where there is a change from a dyssymmetric nonpurposeful relationship in the midface of the muscles to a purposefully organized and symmetrically functional arrangement after primary surgery.

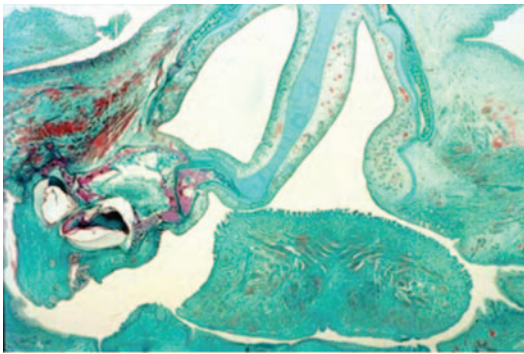
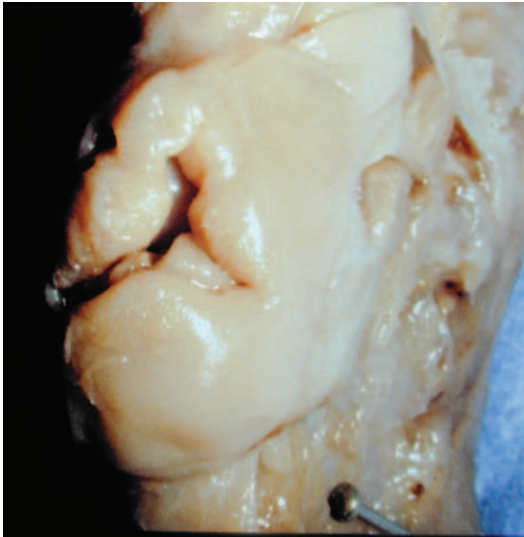


FIGURE 18-2 Dyssymmetric muscles distorting bones (and other important anatomic elements) in a human fetus.

Orthognathic surgery to advance or lengthen the retruded maxilla is accurate, and it can be performed without bone grafts. Distraction can certainly be performed without bone grafts, but accuracy may in fact be more difficult. Conventional-step osteotomy can be used to avoid ramping and to achieve good predictability in the position of the advanced maxilla. Reverse-step osteotomy can be used to achieve overlapping bony segments, thus obviating the need for bone grafts in many cases (Figure 18-5).

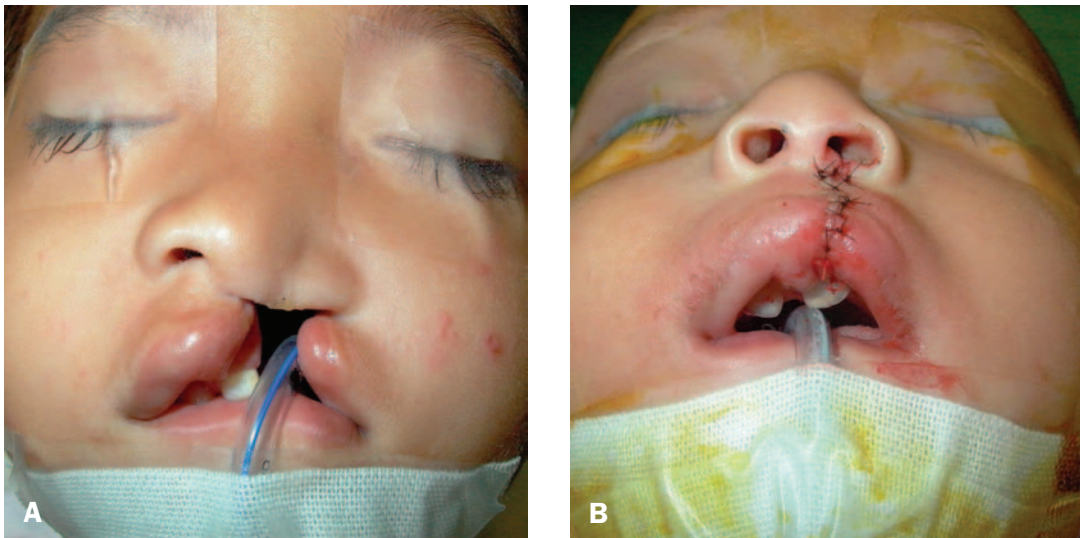


FIGURE 18-3 A, Dyssymmetric nonpurposeful muscle relationship in the midface of an unrepaired complete cleft lip and palate. B, The deformity was changed by primary functional surgery to a purposeful organized and symmetrically functional arrangement.

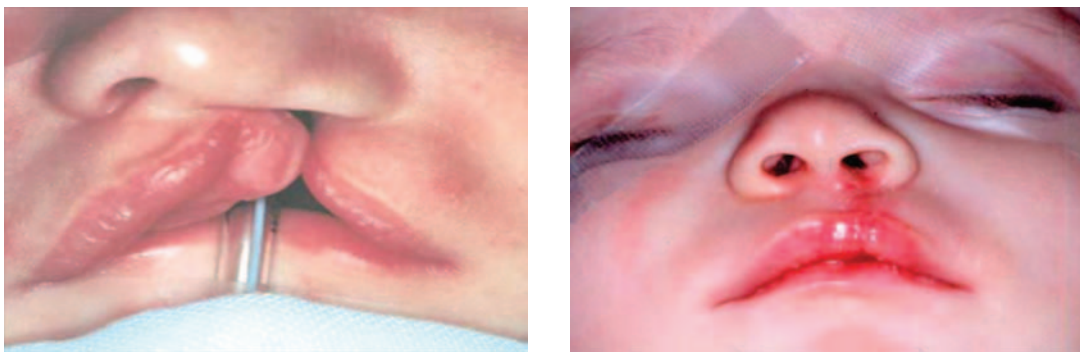


FIGURE 18-4 Early orthognathic surgery, where the muscles are the distractors. Note the improved symmetry and balance of the face only 7 days after physiologic primary surgery.

Figure 18-6 demonstrates a patient who underwent Le Fort I advancement osteotomy, bilateral sagittal splitting osteotomy, and concomitant removal of four impacted third-permanent-molar teeth. The operating time was 2 hours and 20 minutes, the hospital stay was less than 2 days, and the estimated blood loss

was 225 cc. Two weeks after the procedure, she was eating pasta, fish, and cooked vegetables. She had a total of three postsurgical visits before returning to her orthodontist for completion of the orthodontic treatment. She has a stable Class 1 canine molar relationship 5 years after her surgery.

Relapse has been a point of discussion with respect to both orthognathic surgery and distraction osteogenesis. It is known that moderate movements, either to advance the maxilla or to superiorly reposition it or some combination of those, are stable.

It is also known that inferior repositioning of the maxilla by the Le Fort I osteotomy is inherently unstable. If bone graft and rigid fixation are added, then this movement is a bit more stable. Le Fort I osteotomy with bone graft, rigid fixation, and concomitant mandibular ramus surgery produces the most stable results.² Very little is known about inferior repositioning of the maxilla by distraction osteogenesis, either with or without concomitant mandibular surgery.

In severe sagittal discrepancies, there is little doubt that with large maxillary movements in the cleft population (and sometimes even in movements that are not so large), late relapse is a problem when conventional orthognathic surgery is performed. That is why distraction appears to be a preferred indication for this circumstance. In spite of this apparent indication for distraction, we must be aware that many of the published papers advocating the use of distraction osteogenesis report maxillary advancement of 6 mm or less. As is the case in all clinical questions, more data are needed to clarify the debate on the issue of relative and absolute indications for one or the other technique.

Can concomitant muscular surgery be done in the adult or pediatric patient with orthognathic surgery? The answer is yes, and therefore at the same operation, muscle symmetry can be achieved, which in turn enhances bone symmetry. On the other hand, there is not really much information reported on concomitant muscle surgery with distraction osteogenesis. With the use of distraction, the bones are driving the muscles, and therefore without muscle surgery, dyssymmetric function will remain at the end of the bone movement. Accordingly, the surgeon is faced with the problem of deciding when to do muscle surgery.

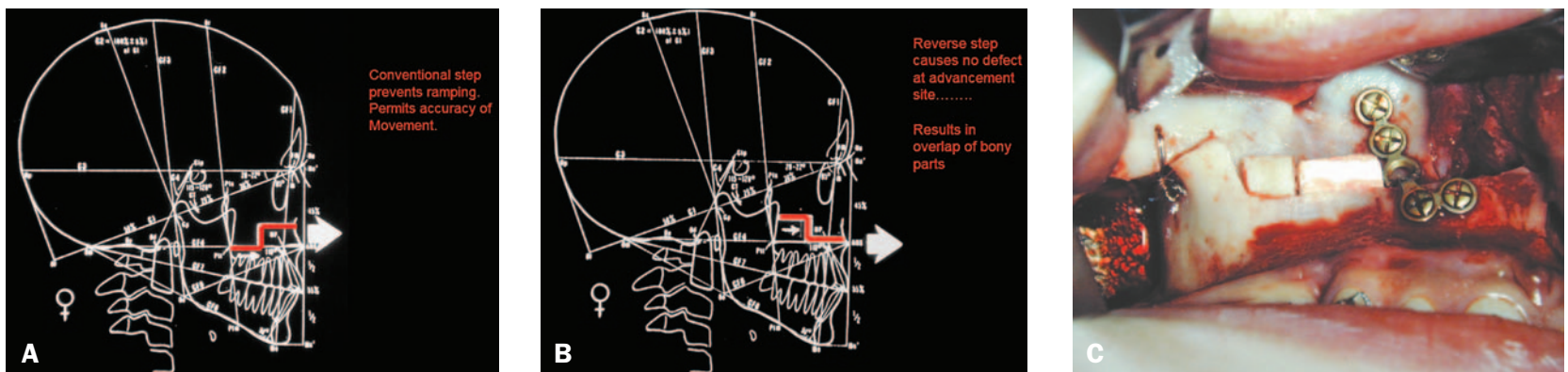


FIGURE 18-5 Traditional-step osteotomy (A) compared with reverse-step osteotomy (B) designed to advance the maxilla. C, Combined wire and rigid fixation.



FIGURE 18-6 This patient underwent Le Fort I osteotomy, bilateral sagittal splitting osteotomy, and concomitant odontectomy of four impacted third-molar teeth. Rapid, efficient treatment is “patient friendly.”

In orthognathic surgery, performing lip (muscle) surgery concomitantly with Le Fort I osteotomy provides access to all of the structures and all of the muscles that need to be reconstructed. The surgeon has direct access to the nasal septum and premaxilla, and once the maxilla has been repositioned to its proper skeletal position, muscular symmetry on a properly placed foundation can be achieved (Figure 18-7).

One issue related to maxillary advancement using orthognathic surgery is timing. At what young age can maxillary osteotomy be safely performed? If there is predominant maxillary

retrusion and the mandible is of relatively normal size and position, notwithstanding a certain unpredictability of even “normal” mandibular growth, then Le Fort I osteotomy can usually be performed as early as the position of the maxillary canine teeth will permit.

If the mandible is not of normal size, then it is more difficult to predict the magnitude and direction of subsequent mandibular growth. There are two possibilities, in addition to the pure maxillary retrusion mentioned above, which can give rise to Class III relationships. There can be predominant mandibular protrusion or there

can be a combination of both maxillary retrusion and mandibular protrusion. With orthognathic surgery, the surgeon can operate in either the body or the ramus of the mandible if necessary, but making the correct diagnosis and deciding on the optimum timing of treatment represent a dilemma, no matter whether distraction or orthognathic surgery is chosen to advance the maxilla.

Orthognathic surgery is safe. In more than 5,000 surgeries performed at our center between 1973 and 2003, the overall complication rate, including infection, bleeding, central nervous system complications, fixation problems, and ocular and ophthalmologic complications, was less than 1.5%.

Distraction forces vary with technique. There are techniques that employ complete osteotomies, incomplete osteotomies, and the so-called sutural technique where no osteotomies are made. It is not known what the global effects are of applying a distraction force to the front part of the midface in a young patient. Is there some form of remote distortion? Is there a differential response from the various parts of the face? Distraction forces have now been measured to occur at the end of distraction, in a magnitude as high as 140 newtons.³ Do these forces redistribute through the cranium, and if so, can there be a resultant change in either the anterior cranial angle or more importantly the sphenoidal angle in young patients (Figure 18-8)?

Both orthognathic surgery and distraction osteogenesis change muscles.^{4,5} Muscle change in orthognathic surgery is acute, whereas it occurs more slowly over the distraction period with distraction osteogenesis. Sheep masseter muscle has demonstrated increased bulk secondary to distraction, but it has also shown dystrophy, atrophy, and sclerosis, as well as some areas of necrosis. More interesting still is that in goat tibia, 20% distracted in length, certain muscle types showed a differential response, and there was a discrepancy in myofiber length as the increase responded to the distraction. This led to muscle instability and muscle contractures. It is known that when one advances the maxilla using traditional orthognathic surgery, particularly when the mandible is of normal size and position, immediate and long-term improvements in the resting tongue posture are often achieved (Figure 18-9). That is helpful from the point of view of mandibular function and can also be helpful in speech.

Adjunctive surgical procedures can be performed concomitantly with traditional surgical maxillary advancement. This is particularly important in patients who have cleft lip and palate. Cleft lip and palate patients need either primary gingivoperiosteoplasty or early secondary alveolar bone grafts to reconstruct the

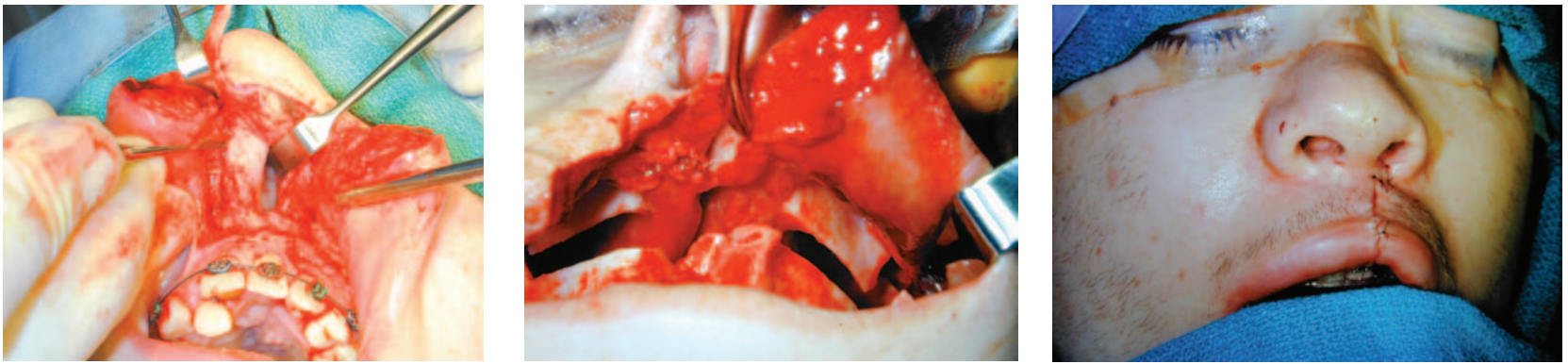


FIGURE 18-7 Complete revision of the cleft deformity at the same time as Le Fort osteotomy allows reconstruction of all of the relevant problems at one operation.

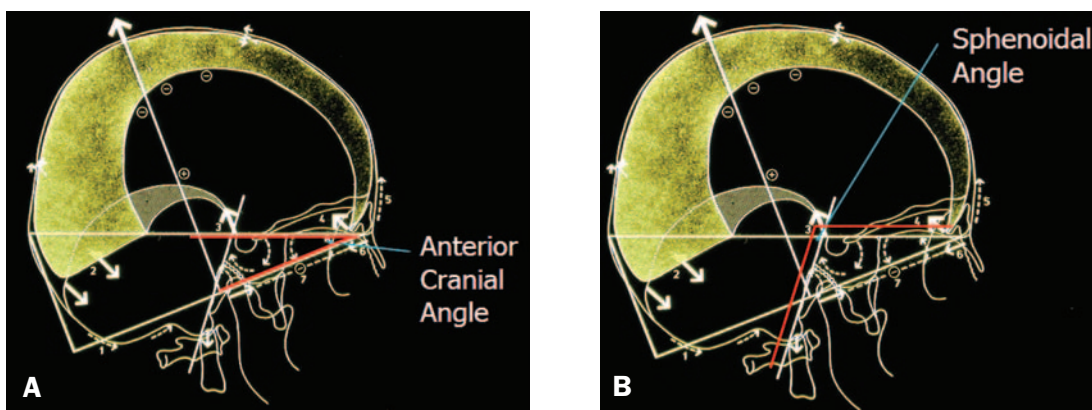


FIGURE 18-8 A, Anterior cranial angle. When this angle increases in size, there is an increased tendency toward a cranial predisposition to a Class III malocclusion. B, Sphenoidal angle. When this angle decreases (closes), there is an increased tendency toward a cranial predisposition to a Class III malocclusion.

alveolar–nostril–skeletal nasal base deformity, irrespective of their need for skeletal advancement of the midface. Distraction osteogenesis cannot meet this need. Frequently, cleft lip and palate patients need alveolar bone augmentation through grafting, and accompanying soft tissue procedures to restore gingival and mucosal tissues. The addition of bone to the cleft alveolus is important not only for normal tooth eruption and periodontal health, but also to reconstruct the skeletal nasal base, the most important constituent of which is an intact nasal floor, equal in height to the noncleft side (Figure 18-10). In the younger patient, at 5 to 6 years of age, there is the opportunity to graft the cleft defect at a critical time and at the same time perform nasolabial muscle surgery to establish functional symmetry,

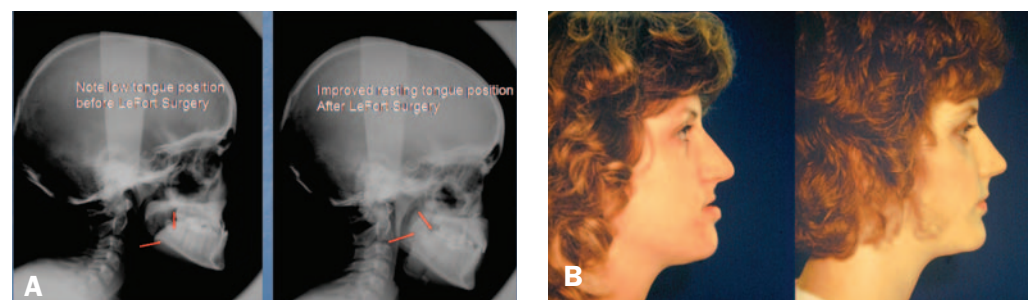


FIGURE 18-9 Maxillary advancement improves the resting tongue position (A) and also provides for lip–nose enhancement (B).

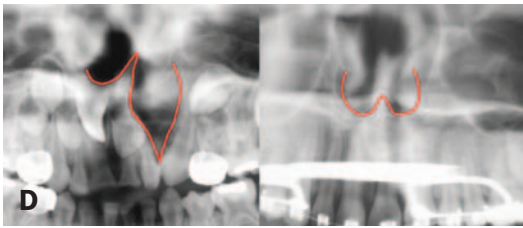


FIGURE 18-10 A, Alveolar defect exposed. This problem is not correctible by distraction osteogenesis. B, A cortical sheet being placed to reconstruct the skeletal floor of the nose. C, A completed cancellous alveolar bone graft. D, Resultant symmetry of the nasal floor on both the cleft and noncleft sides.

to relapse, even after large skeletal movements, owing to the new bone formed in the distraction gap. By definition, the need for conventional bone graft is obviated. It is known that during the retention period, the newly formed bone gradually becomes lamellar and gets mineralized. It is also known that bone cells respond to mechanical stimulation by gene expression. When sheep maxillary bone was distracted daily for 15 days, elevated levels of *c-jun* and *c-fos* mRNA were found after 8 days of distraction. These genes are related to mechanotransduction and are important for bone development.⁶

Maxillary distraction in cleft patients can be performed in three ways: (1) surgically assisted maxillary protraction using a face mask, (2) rigid extraoral devices, and (3) internal devices. Rachmiel and colleagues have shown results that demonstrate great advantage using distraction osteogenesis methods, with better stability over time and further maxillary growth when using the method in growing patients.^{7,8} In cleft palate patients, especially in severe retrusion, the method of distraction osteogenesis appears to be preferable over conventional orthognathic surgery, achieving greater advancement, with less tendency to relapse over time (Figure 18-12).

which in the long term enhances subsequent facial growth. Good primary muscle surgery remains the key to providing the best possible facial growth and thereby diminishing the need for later orthognathic surgery or distraction osteogenesis (Figure 18-11).

Distraction Osteogenesis

Distraction osteogenesis, a procedure initially developed for limb lengthening, has been used to advantage in the jaws since the 1990s. It involves the lengthening and shaping of deformed and deficient bone by surgical fracture or osteotomy, and subsequent slow distraction of the bony parts with specially designed mechanical devices. This gradual stretching of the tissues permits bone callus formation and adaptation of fibromuscular attachments.

In cleft lip and palate patients, the maxilla is often difficult to mobilize in conventional orthognathic surgery, because of scarring from previous operations in the soft or hard palate or lip closure. Advancement of the retrusive maxilla is usually attempted through one of the Le Fort osteotomies, with or without additional bone graft, in order to reestablish the facial balance and occlusion. Maxillary retrognathism associated with cleft lip and palate has a tendency to relapse after conventional orthognathic surgery, but when distraction osteogenesis is used to advance the cleft maxilla, there seems to be a reduced tendency



FIGURE 18-11 Physiologic primary muscle surgery prevents facial dyssymmetry and aids subsequent balanced facial growth.

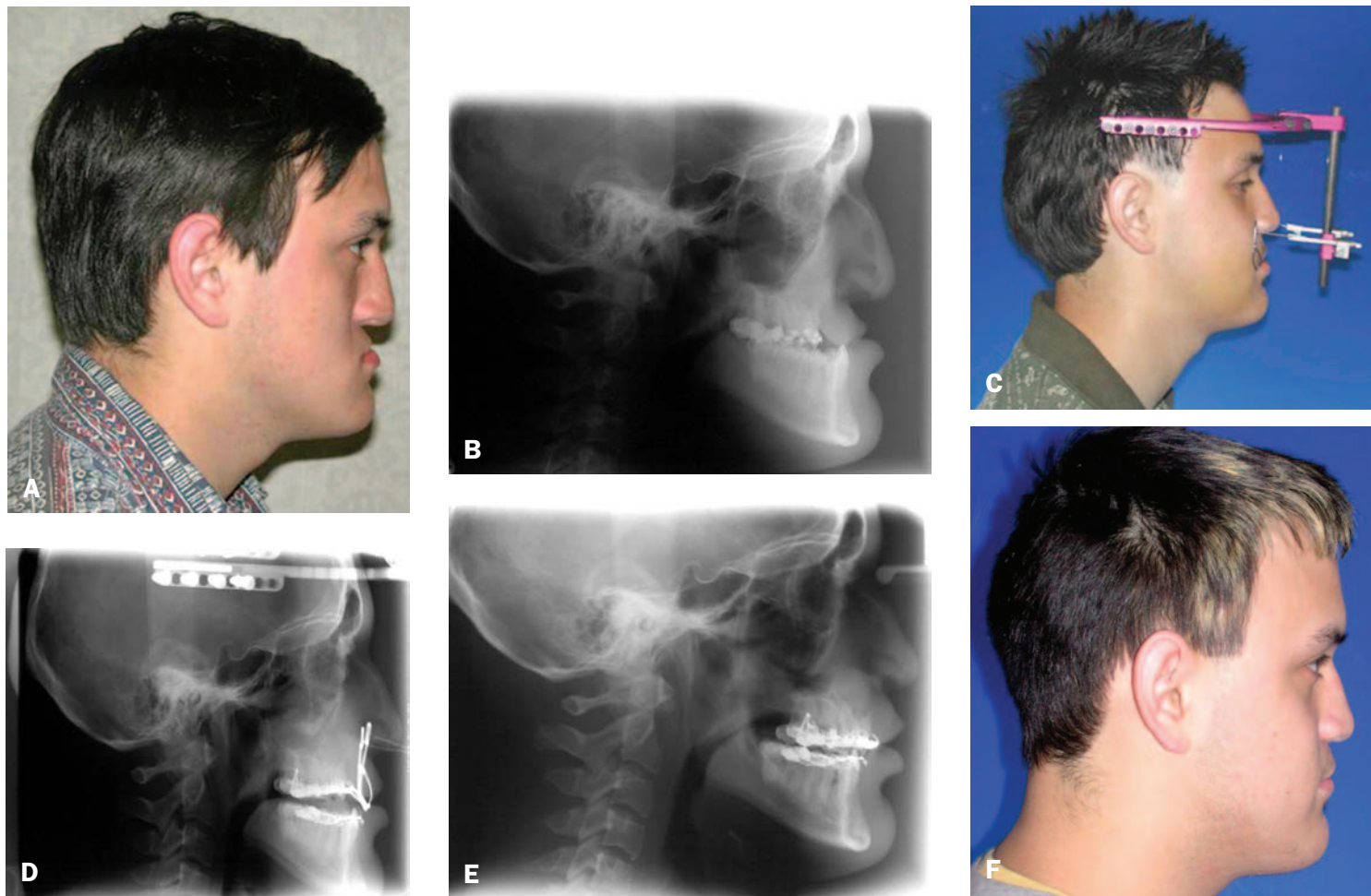


FIGURE 18-12 A, Pretreatment profile of young man with severe maxillary retrusion, secondary to poor primary cleft lip and palate surgery. B, Pretreatment cephalometric radiograph. C, External distraction device in place. D, Cephalometric radiograph early in the distraction process. E, Cephalometric radiograph showing the final position of the distracted maxilla. F, Posttreatment profile, 1 year following distraction of the maxilla.

Summary

In summary, orthognathic surgery is safe, generally predictable, relatively accurate, time efficient, and cost efficient, and it has a long history. Distraction osteogenesis is also safe, and it provides a method that can produce significantly greater magnitude of advancement, but it is more time consuming and costly than orthognathic surgery.^{9,10} Orthognathic surgery is a constellation of corrective procedures to which distraction osteogenesis should be added. Distraction osteogenesis should not be thought of as a stand-alone all-inclusive treatment modality. The acid test for both orthognathic surgery and distraction osteogenesis is the extent to which either technique can restore the “normal” development of a once “pathologic” pattern of facial growth. Unfortunately, this issue remains largely unresolved.

Acknowledgment

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Clinical Experience with Piezosurgery

Astrid Reichwein, J. Thomas Lambrecht, Kurt Schicho, Gerhard Undt and Rolf Ewers

Physical and Historical Background

The “piezo effect” is based on physical interactions and phenomena of basic electric and mechanical dimensions, such as electric field strength, polarization, and tension and extension in crystalline bodies. The piezoelectric effect is used in numerous technical applications, such as measurement technologies, microphones, loudspeakers, special motors, inkjet computer printers, frequency generators for quartz clocks, and many other electronic devices. A well-known and widespread application in medicine is ultrasonography.¹

The French physicists Jacques and Pierre Curie, in collaboration with Gabriel Lippmann, discovered around 1880 that by the application of mechanical pressure and power to body surfaces (eg, quartz, turmalin, barium titanate), a measurable electric loading is induced.^{2,3} Therefore, it was also possible to realize the reverse effect: in an electrical field, it is possible to shape a piezoelectric material (Figure 19-1). This

has been a milestone in micro- and nanotechnology for the subsequent rapid development of numerous applications.

The Greek word *piezo* originally meant *pressure*. Today it is used for the description of the shift direct piezo effect, as well as the inverse and/or reciprocal piezo effect. The direct piezo effect causes a shift of superficial potential difference by using mechanical pressure on a crystalline, anisotropic material (dielectricum). This effect cannot be observed in symmetric and homogeneous crystal (eg, NaCl).

The crystalline structure of the material is crucial for the piezoelectric effect, as well as the exchange of the positive and negative charges of an elementary cell against each other (anisotropy). From the chemical or physical point of view, the reciprocal piezo effect can be interpreted as the exact conversion of the direct piezo effect. It is the result of the nanometric deformations of the crystal in an electric field. The definite polarization of the molecules plays the decisive

role. This dynamic behavior is being used to transform the longitudinal and/or transverse ferroelectric effect into a surgical cutting effect.

Since the early 1980s, ultrasonically based instruments have been used in medicine. Horton and colleagues initially reported on bone removal with ultrasonically driven instruments.⁴ Torrella and colleagues and Vercelotti took up this technology again.⁵⁻⁹ So-called Piezosurgery (Piezosurgery by Mectron Medical Technology, Carasco, Italy) allows for improved safety and precision for osteotomies and for optimum tissue healing.

In general, there is a wide range of possibilities of piezotechnology in oral and maxillofacial surgery. Exemplary applications of this method in maxillofacial surgical procedures within the oral cavity are preimplantologic tooth removal under maximal bone preservation, presinus grafting preparation, and lateralization of the inferior alveolar nerve.

Materials and Methods

Technical Setup

The Piezosurgery device consists of a handpiece with different kinds of working pieces (Figure 19-2), which is connected to the central electronic source (connecting box). A silicon tube connects the sterile cooling liquid with the ultrasonically driven engine (Figure 19-3). Various diamond-made working pieces and frequencies can be selected for treatment of different tissue densities. The flow of the cooling liquid can also be adjusted. The ultrasound vibration of the instrument's extension can be set to micromovements between lengths of 20 and 200 μm . The available frequency is 20,000 Hz (ie, 20,000 micromovements per second).

Applications

Sinus Grafting

Sinus floor elevation and the following sinus grafting with an algae-derived material are now a standard procedure in preprosthetic surgery. The piezoelectric method has proven to be a valuable alternative to traditional sinus surgery because the risk of perforating the schneiderian

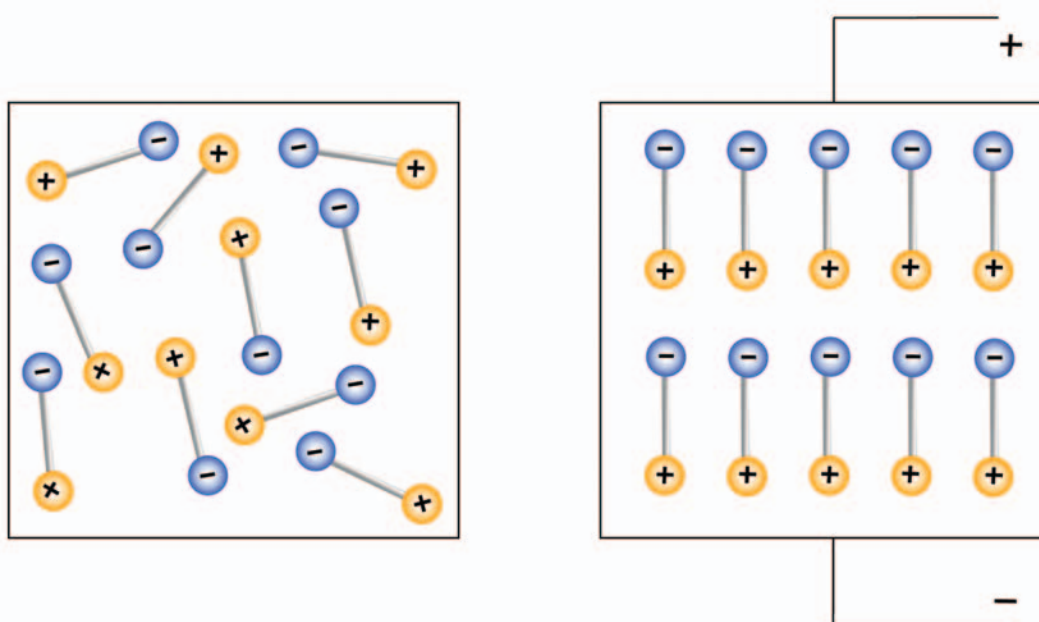


FIGURE 19-1 Illustration of the basic principle of the piezo effect. In a piezoelectric material, the positive and negative charges are distributed randomly (left). Application of an electric field results in defined orientation of the charges.

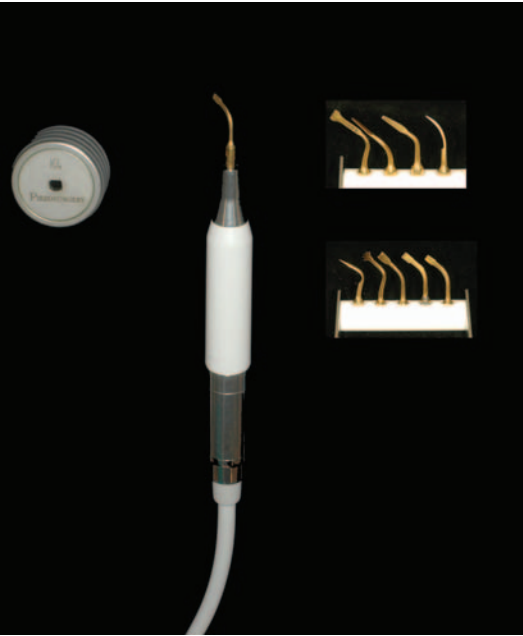


FIGURE 19-2 Tools of the Piezosurgery device. For different indications, various tools are available. A diamond tool facilitates the bone removal (eg, in the vicinity of neural structures), for example during an enlargement of the mental foramen. The sawing instrument allows precise osteotomies. Working pieces with polished surfaces are ideal for elevating soft tissue and separating, for example, the scheiderian membrane from the maxillary sinus wall.



FIGURE 19-3 Working unit of the Piezosurgery device. There are different power levels in the control unit. With the four different bone levels, various qualities of bone can be cut. The “perio” level, for example, allows careful removal of concretions. The control unit operates the working piece through a foot pedal.

membrane can be clearly reduced by preparing a deep-lying, horizontal channel with a diameter of 7 to 9 mm into the lateral sinus wall with the Piezosurgery device (Figure 19-4 Movies 19-1 and 19-2).

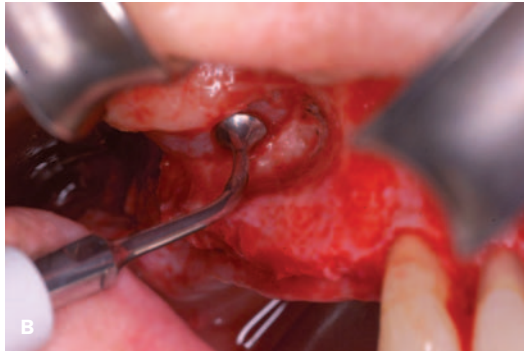
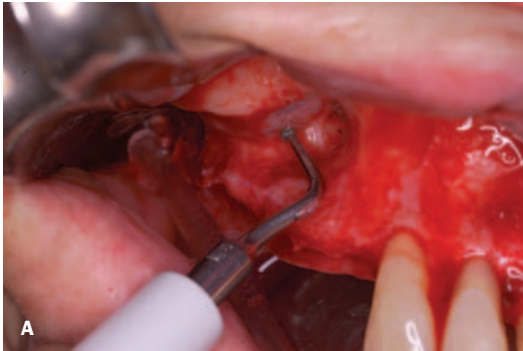
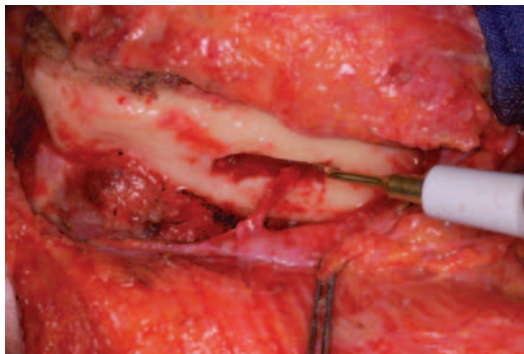


FIGURE 19-4 A, Intraoperative situation of a sinus grafting procedure; remaining bone lamellae of the lateral maxillary sinus wall can be removed without harming the sinus mucosa, in this case, with a ball diamond. B, Then the sinus mucosa can be elevated with the smooth, noncutting working piece.

Pedicated Sandwich Plasty

The horizontal two-step pedicled sandwich plasty is a new surgical form of treatment for the narrow edentulous alveolar ridge. This procedure is a result of careful planning and execution of horizontal augmentation by splitting of bone with or without lateralization of the inferior alveolar nerve. In this case, the osteotomy for the horizontal two-step pedicled sandwich plasty has been performed with a Piezosurgery device (Figure 19-5, Movies 19-3 and 19-4).¹⁰



Nerve Lateralization

The inferior alveolar nerve can be prepared cautiously by Piezosurgery devices (eg, in cases of preprosthetic surgery, mandibular osteotomy, wisdom tooth removal, and cystectomy and in mapped case during a partial mandibular resection) (Figure 19-6). The traditional preparation of the inferior alveolar nerve and the osteotomy

FIGURE 19-6 Intraoperative situation of a partial mandible resection; preserving the inferior alveolar nerve is the aim. First, the mental foramen is enlarged by the use of a ball diamond working piece. For total neurolysis for freeing the nerve, a channel osteotomy next to the mandibular canal is performed by a sawing working piece. Finally, the nerve is loosened in its total length.

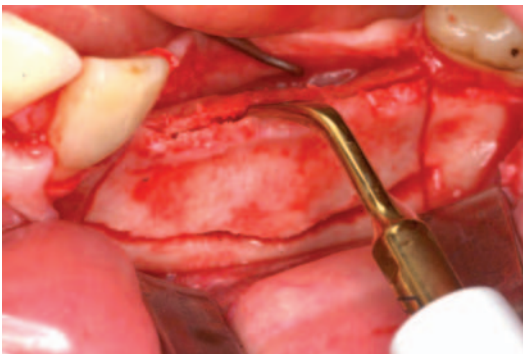


FIGURE 19-5 Intraoperative situation of a pedicled sandwich plasty procedure. The indication for this new method is a narrow alveolar ridge of less than 5 mm in width, which requires horizontal augmentation for later placement of dental implants. In the first step of this technique, a full mucosal flap is prepared; then a crestal, two vertical, and one lower horizontal osteotomy are performed with the Piezosurgery device.

of the mental foramen with drilling instruments cause a possible laceration of the inferior alveolar nerve (Movie 19-5).

Tooth Removal

Bone-sparing tooth removal (eg, following tooth transplantation). The advantage of careful enlargement of the periodontal gap can be performed by dabbing piezosurgical preparation. After careful piezosurgical periodontal bone removal, it is not necessary to lever up the tooth by Bein’s lever; therefore, the alveolar crest bone quantity is preserved. In particular, piezosurgical treatment of children under local anesthetic conditions without a drilling sound and vibration is a positive attribute of this technique (Figures 19-7 A & B).

Osteotomy

In cases of orthodontic treatment, in which an osteotomy is required, it can be performed very

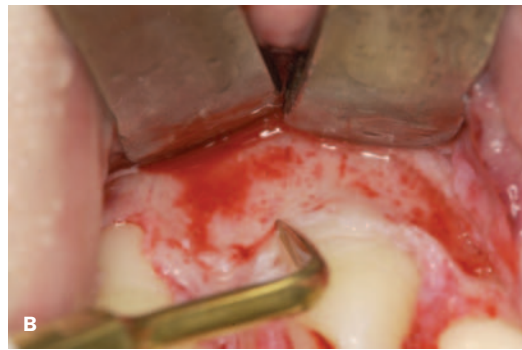


FIGURE 19-7 A, Intraoperative situation of an impacted tooth removal. In this case, orthodontic adaptation of the upper right canine was not indicated; a careful pericoronary and periradicular osteotomy with different chisel working pieces had been performed. B, Application of the Piezosurgery device. Especially under local anesthetic conditions, this procedure allows gentle surgical treatment of children.

carefully without the risk of harming any tooth or soft tissue structures (Figure 19-8, Movie 19-6).

Lysis of Temporomandibular Joint Ankylosis

The following is a case report of a female, age 36 years. Following polytrauma with bilateral high condylar neck fractures, the patient underwent open reduction and microplate osteosynthesis on both sides. Six months later, the microplates were removed and lysis of a beginning ankylosis was performed at another hospital. Another 8 months later, the patient presented again at our hospital with steadily decreasing mouth opening. A computed tomographic scan revealed the development of a bony ankylosis on the right and of a fibrous ankylosis on the left (Figure 19-9).

The patient's preoperative clinical status was as follows: maximum interincisal distant (IID) 12 mm, protrusion 1 mm, and laterotrusion 1 mm. There was no articular or muscular pain.

Bilateral lysis of the ankylosis and resection of the coronoid process were performed. On the right side, the bony masses on the medial aspect of the condyle were resected with the aid of

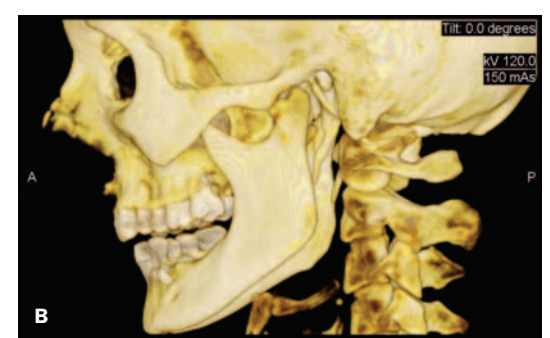
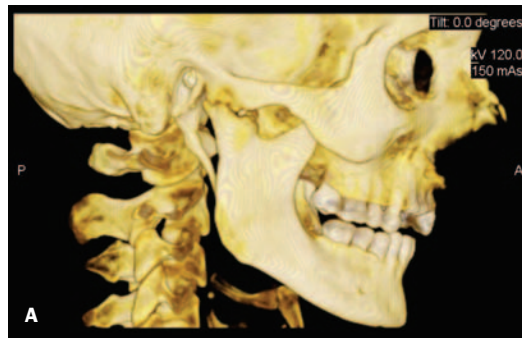


FIGURE 19-9 A and B, Three-dimensional computed tomographic reconstruction of the initial situation.

Piezosurgery (Movie 19-7, Figure 19-10). The resection of the coronoid process also was carried out with the aid of Piezosurgery (Movie 19-8, Figure 19-11). The reshaped joint surfaces were separated by a Silastic membrane, which was removed 4 months after surgery.

The clinical outcome 1 year after surgery was as follows: maximum IID 30 mm but still with severe limitation in protrusion and laterotrusion.



FIGURE 19-8 Intraoperative situation of a segmental osteotomy of the frontal region in the lower jaw.

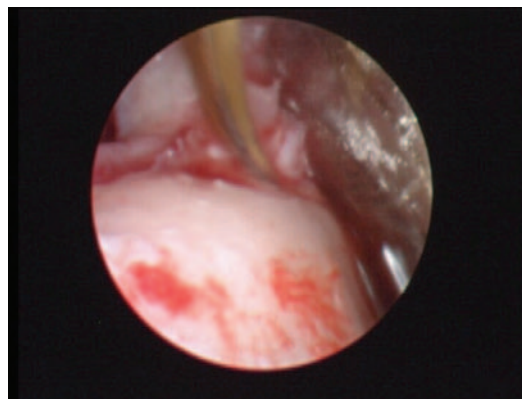


FIGURE 19-10 Intraoperative situation: removal of ankylotic masses.

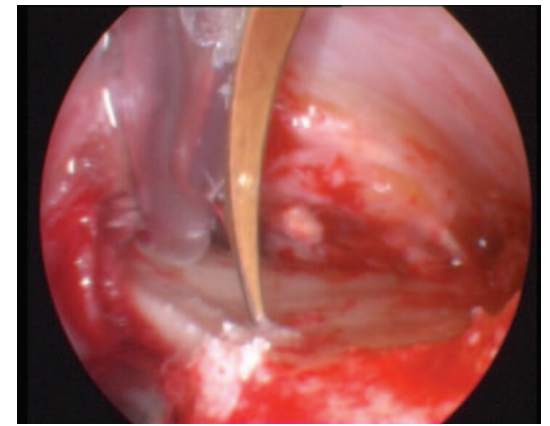


FIGURE 19-11 Intraoperative situation: resection of the coronoid process.

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Simultaneous Correction of Three-Dimensional Maxillary Deformity by the Le Fort I Osteotomy and Distraction Osteogenesis Technique

William H. Bell, Lecio Pinto, Stephen Chu, Peter Buschang and Cesar Guerrero

Transverse maxillary deficiency is present in many adults seeking orthodontic treatment.¹ Since the use of functional appliances or orthopedic devices in adults is characterized by instability,^{2,3} damage to the periodontium,^{4,5} and compromised facial esthetics,⁶ the effective treatment options to expand the maxilla after the maturation of facial skeleton are the multi-segment Le Fort I expansion procedures^{7,8} and surgically assisted maxillary expansion (SAME).⁹ Although SAME overcomes some of the described problems and is associated with improved stability,¹⁰⁻¹² it is limited to only the transverse dimension. Anterior-posterior disharmony and vertical disharmony, frequently associated with the transverse problem,¹³ require subsequent orthognathic surgery, incurring its costs and the risks of an additional surgical procedure under general anesthesia. Le Fort I osteotomy offers the possibility of three-dimensional movements but is considered one of the least stable orthognathic procedures.¹⁴⁻¹⁶ Additionally, Le Fort I osteotomy has been related with vascular complications,¹⁷ difficulties in positioning and stabilizing the segments, oronasal and/or oronasal fistulae, and loss of gingival papillae with underlying periodontal defects.¹⁸ Owing to the limitations and complications of SAME and LFI-E, an alternative approach is warranted.

The challenge to achieve simultaneous three-dimensional maxillary repositioning prompted us to develop a more predictable, versatile, and stable surgical orthodontic technique for treatment of selective deformities. We hypothesized that a combination of distraction osteogenesis, distraction histiogenesis, and individualized lateral maxillary osteotomy designs would achieve these goals in a single procedure. The maxillary

segments would be repositioned as planned in the sagittal and vertical planes of space by variably designed lateral maxillary osteotomies and transversely by distraction osteogenesis (Figure 20-1). Thus, the best features of the two techniques are combined into a single procedure. Nonextraction and extraction orthodontic treatments are options.

To surgically achieve a maxilla of normal size and proportions mandates variable complex translational and rotational movements of the

jaws. Three-dimensional maxillary deformities may be associated with crowded anterior teeth, a narrow and tapered arch form, impacted and/or blocked-out canines, and variable sagittal and vertical maxillary deformities. In the past, such problems have frequently mandated the use of two- or three-stage surgical techniques and extraction of premolars. When, however, the planned maxillary repositioning does not include known problematic unstable maxillary movements (ie, excessive widening or vertical

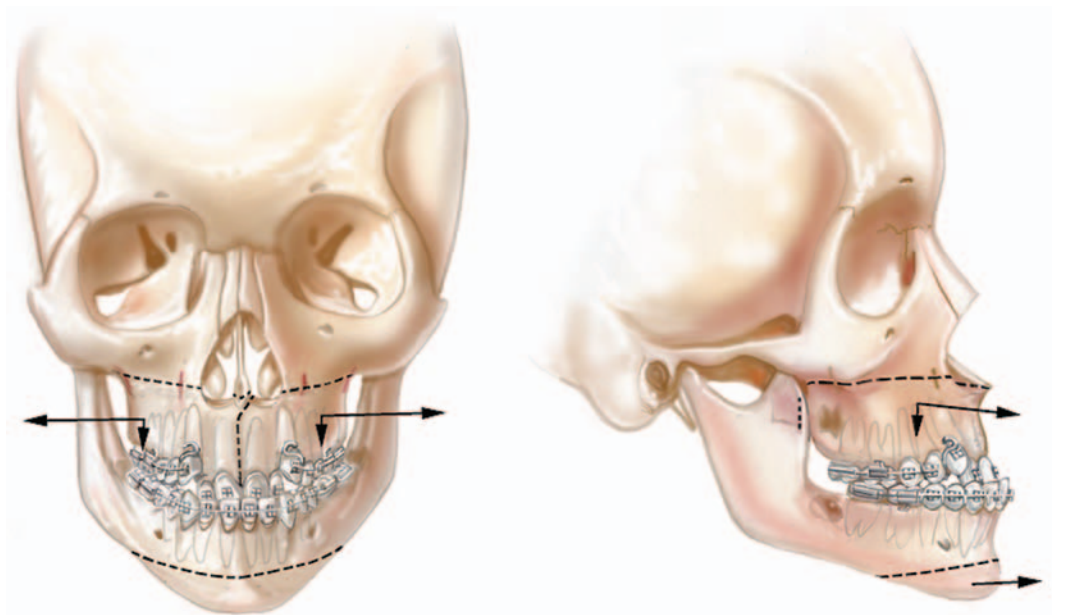


FIGURE 20-1 3-D Repositioning. Anterior-posterior, vertical, and transverse maxillary hypoplasia associated with Class III malocclusion, crowded maxillary anterior teeth, and blocked-out canines. Mandibular dentition decompensated by presurgical orthodontics. Simultaneous three-dimensional surgical correction of the skeletal deformity by anterior-posterior, vertical, and transverse repositioning of the maxilla. A two-segment Le Fort I osteotomy repositions the maxilla as a single unit, which is appropriately adjusted in the transverse dimension by a palatal distraction appliance. Arrows indicate three-dimensional directional changes of the maxilla.

lengthening) long-term stable positional changes can be expected.

Clinical and Biologic Foundation

The clinical basis for using distraction osteogenesis and histiogenesis in the anterior maxilla is founded on the need for transverse widening of the crowded, tapered, and constricted anterior maxilla and associated soft tissues. However, the integrity of the gingival tissue and interdental papilla in this vital esthetic zone may be compromised by immediate widening in excess of a few millimeters. In contrast, slow incremental expansion of the anterior segments by distraction osteogenesis allows adequate stretching of the gingival tissue and periodontal ligament to widen the anterior maxilla and subsequently reposition the adjacent teeth into the distraction gap after an appropriate consolidation period. The gingiva responds favorably to gradual stretching during distraction histiogenesis. The initial mild inflammatory and reactive changes observed during distraction in the first few weeks of consolidation are followed by regenerative changes with neohistogenesis to restore the structural and functional integrity of the gingiva.¹⁹⁻²⁰

Because many maxillary deformities are, in fact, three-dimensional in nature, treatment results frequently fall short of the ideal result with the use of osteotomy designs that focus exclusively on the transverse dimension. In one study, a group of 78 patients were treated by surgically assisted widening of the maxilla with virtually no consideration of the vertical or anterior-posterior dimension.¹⁹ Current one- or two-stage surgical techniques may not achieve ideal functional, stable, or esthetic results. Moreover, patients may not accept two-step surgery¹³ because of the need for two general anesthetics and increased costs. This chapter introduces a new surgical technique designed to three-dimensionally reposition the maxilla by combining distraction osteogenesis with orthognathic surgery (see Figure 20-1). Known problematic unstable maxillary movements are corrected by distraction osteogenesis. Variable individualized lateral maxillary osteotomy designs are used whenever feasible to control the sagittal and vertical positional changes without bone grafting.

Biologic-Biomechanical Considerations

When we began to consider the possibility of simultaneous three-dimensional repositioning of the maxilla by a combination of orthognathic surgery and distraction osteogenesis, there were no reported clinical or biologic studies to support its use. Previous investigations, however, have demonstrated that maxillary widening was possible when accomplished by distraction osteogenesis or by Le Fort I osteotomy.^{10, 11, 19-25}

Success with simultaneous three-dimensional repositioning of the maxilla depends on manipulating the distraction callus before the interzone ossifies. Radiographic analysis of the distraction gap at the end of the distraction period and at the beginning of the consolidation period typically shows a central radiolucent interzone surrounded by newly formed bone trabeculae emanating from the edges of the distracted segments.¹⁹ At this stage, the interzone is occupied by extensible collagen fibers. The shape of the distraction regenerate can be changed by anterior traction or by digital manipulation of the mechanically weak callus. However, the window of opportunity for such a change is relatively short (between 2 and 3 weeks after distraction). The treatment goals are based on clinical, occlusal, and cephalometric analyses.

It can be logically asked, "How does bone healing take place when micromotion is occurring at the osteotomy sites during three-dimensional repositioning?" As the maxilla is slowly widened by distraction osteogenesis, there are small, concomitant, incremental positional changes at the closely aligned lateral maxillary osteotomy sites. However, the apparent occlusal and skeletal stability without delayed union or nonunion gives support to our clinical hypothesis that bone healing occurs with three-dimensional repositioning of the maxilla and that absolute stability of the repositioned segments is not necessary for osseous healing.

Patients and Methods

Surgical orthodontic treatment of noncleft or nonsyndromic patients manifesting three-dimensional maxillary dentofacial deformities is the focus of this chapter. Based on our experience with more than 50 selective patients in recent years, a new intraoral maxillary repositioning technique has been developed to facilitate simultaneous correction of the transverse, vertical, and sagittal dimensions of selective maxillary deformities without bone grafting by Le Fort I osteotomy and distraction osteogenesis (3-D LFI-DO). All surgical procedures are performed under general nasotracheal anesthesia in an ambulatory center.

Treatment Planning

Clinical, cephalometric, and occlusal analyses are employed to develop a systematic treatment plan to correct the deformity in all three planes of space. Long-term success mandates an assessment of the patient's age, future growth potential, psychosocial factors, and patient compliance.

Dental casts are analyzed in the anterior-posterior, transverse, and vertical planes of space using either direct measurements, occlusogram analyses, most recently, three-dimensional cone

beam computed tomography (3-D CB CT) (Figure 20-2, A-I) and virtual surgical imaging. Maxillary arch width, form, length and depth, curve of Spee, curve of Wilson, and incisal inclination are used to determine the amount of expansion necessary. Maxillary expansion by distraction osteogenesis is used when maxillary transverse deficiency exceeds 6 mm.

When relatively small expansion is indicated (less than 5 mm), traditional segmental Le Fort I osteotomy (LFI-E) is employed with individualized transverse widening. The lateral maxillary osteotomy design is key for planning predictable maxillary sagittal and vertical positional changes. The repositioning vector is based on a correlative analysis of the lateral cephalometric prediction tracing, visual treatment objective, model surgery, and reconstructed 3-D CB CT scan (see Figure 20-2, A-I). Templates traced from the lateral cephalogram (taken in the natural head position with the lips relaxed) are used to simulate the desired sagittal and vertical osseous and soft tissue changes based on clinical assessment and stability issues. After the position of the maxillary osteotomy site is traced on the lateral cephalometric tracing, the maxillary template is repositioned to simulate the planned surgical result and retraced in the desired occlusion. The calculated millimetric positional changes are the basis for three-dimensional surgical repositioning of the maxilla. Software programs are used as treatment planning adjuncts.

Excellent bone stock is usually available in the zygomatic buttresses and roots of the zygoma for stabilization of the distraction osteogenesis appliance. The bone stock in the anterior maxilla (infraorbital and piriform rim areas), however, is variable. Here the Le Fort I bone segment and/or anterior dentition are used to stabilize the distraction appliance. A 3-D CB CT²⁶ scan and stereolithographic model²⁷ are useful adjuncts for planning distraction osteogenesis and assessing the bone stock available anteriorly and posteriorly (see Figure 20-2, A-I). The evolutionary development of cone beam technology is driven by the clinician's need to plan and evaluate the hard and soft tissues of the face precisely in three dimensions. A single cone beam computed tomographic (CT) scan taken in less than a minute, in a convenient office setting with safe exposure to radiation at an affordable cost, is presently our standard of care for most new deformity patients who enter our office. Within the next 5 years, the majority of surgeons and orthodontists involved in planning and managing treatment of facial deformity will have this technology available either in or near their office. These studies elucidate the angular and linear positions of the teeth, bone, and soft tissues in three dimensions. Postoperative changes visualized on the CT scan of the distracted maxilla after surgery aid in

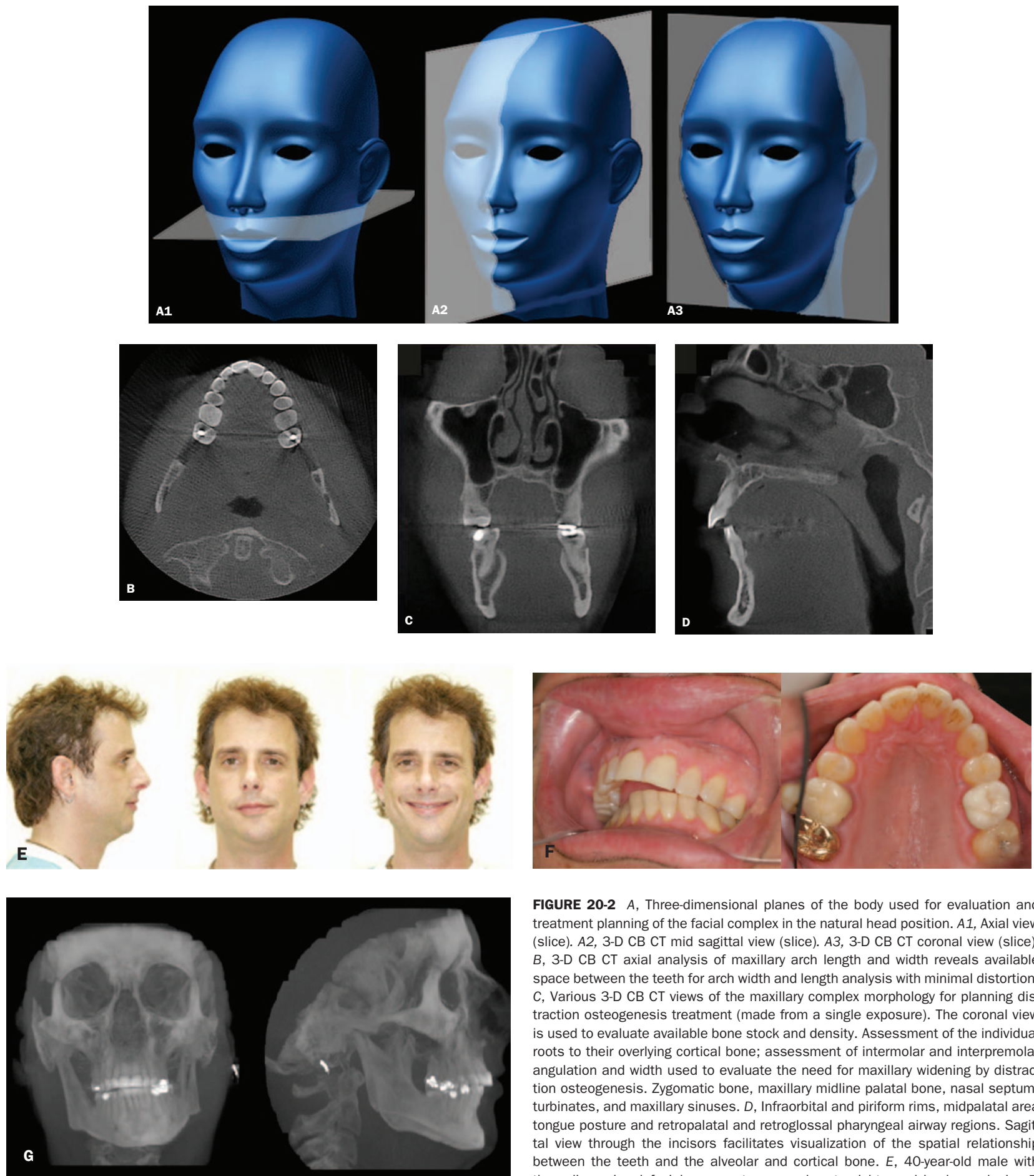


FIGURE 20-2 A, Three-dimensional planes of the body used for evaluation and treatment planning of the facial complex in the natural head position. A1, Axial view (slice). A2, 3-D CB CT mid sagittal view (slice). A3, 3-D CB CT coronal view (slice). B, 3-D CB CT axial analysis of maxillary arch length and width reveals available space between the teeth for arch width and length analysis with minimal distortion. C, Various 3-D CB CT views of the maxillary complex morphology for planning distraction osteogenesis treatment (made from a single exposure). The coronal view is used to evaluate available bone stock and density. Assessment of the individual roots to their overlying cortical bone; assessment of intermolar and interpremolar angulation and width used to evaluate the need for maxillary widening by distraction osteogenesis. Zygomatic bone, maxillary midline palatal bone, nasal septum, turbinates, and maxillary sinuses. D, Infraorbital and piriform rims, midpalatal area tongue posture and retropalatal and retroglossal pharyngeal airway regions. Sagittal view through the incisors facilitates visualization of the spatial relationship between the teeth and the alveolar and cortical bone. E, 40-year-old male with three-dimensional facial asymmetry secondary to right condylar hyperplasia. F, Asymmetric Class II malocclusion, asymmetric occlusal view. G, 3-D CB CT imaging: AP and lateral cephalograms.



FIGURE 20-2 continued.
H, Demonstration of right condylar hyperplasia and (bottom) left advanced condylar resorption. I, Facial reconstruction.

planning necessary secondary movements. Additionally, the radiodensity changes of distraction regenerate are evaluated before and during the consolidation period. These assessments are valuable in estimating the duration of stabilization.

Presurgical Orthodontic Preparation

The goal of presurgical orthodontics is mandibular arch leveling and alignment (Figure 20-3). Before maxillary arch expansion, the transverse tipping of the maxillary teeth is decompensated and the mandibular arch leveled and aligned. This is essential because the maxilla is expanded and repositioned to fit within the confines of the mandibular arch. This goal is usually accomplished within 2 to 6 months. The amount of maxillary expansion, however, is not necessarily limited or mandated by the mandibular arch width. In cases of severe transverse mandibular arch constriction and crowding, symphyseal widening is accomplished simultaneously to compensate for maxilomandibular disharmony and associated dental crowding.²⁸ In selected cases, in which patient compliance is an issue, premolars are extracted to simplify and shorten treatment. In such cases, the transverse facial width and smile may be compromised. The Hyrax expansion appliance is designed according to the location, direction and amount of widening necessary. The mesial and distal arms are soldered to the lingual surfaces of the first premolars and first molar bands, respectively. Bilateral large wires (0.051 inches) are welded from the anterior to the posterior bands to increase the device rigidity and improve the control of the maxillary segments during expansion (see Figure 20-3, A-H).



FIGURE 20-3 Orthodontic preparation. A and B, All anterior and posterior mandibular teeth are banded and bonded (Figure 20-4 A & B). A tooth-borne distraction device is designed according to the location, direction, and magnitude of transverse widening. The basic distraction device consists of a 7, 9, 11, or 12 mm Hyrax screw. The distal arms are soldered to the lingual surfaces of the molar bands, and the mesial arms are soldered to the lingual surfaces of the premolar bands to increase device rigidity, control expansion, and facilitate postexpansion positional changes of the maxilla. A large segmental expansion wire (0.051 inches) is soldered from the premolar to the molar bands, thereby reducing the possibility of adverse movements and forces. Large metal traction hooks are soldered to the expansion wire in the canine region to facilitate rapid positional changes of the maxilla with training elastics during the early postsurgical window of opportunity (2–2½ weeks after distraction). The tooth-borne device is designed to avoid any contact with the palatal mucosal pedicle. The appliance is usually cemented to the patient's teeth 2 to 7 days prior to surgery. Either nonextraction or extraction orthodontic treatment is optional. C, 3-D maxillary deficiency associated with anterior crowding and blocked out canines and transverse deficiency. D, Presurgical decompensation of dentition.

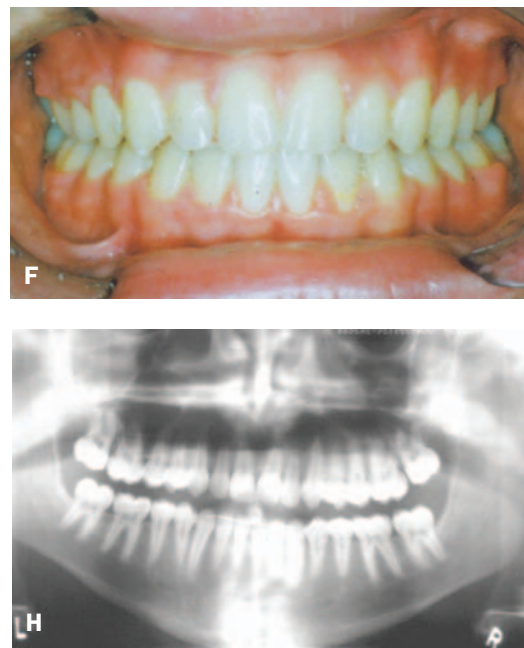
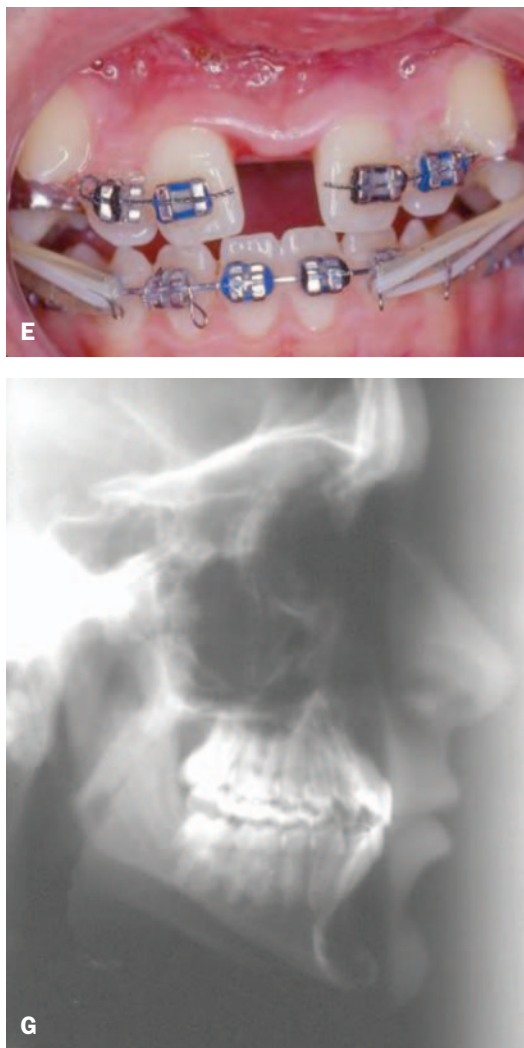


FIGURE 20-3 continued. *E*, Distraction gap created by 10 mm maxillary expansion. Class II elastic traction. *F*, Post treatment occlusion achieved by 3 D Le Fort I distraction osteogenesis without dental extractions. *G*, Skeletal, dental and soft tissue harmony after orthognathic surgery. *H*, Final occlusion without root resorption.

Positioning the Hyrax Expansion Appliance

The magnitude and direction of planned positional changes of the maxillary dental-skeletal complex are factored into the plan to widen the maxilla. Maxillary positional changes are nonparallel, opening maximally anteriorly and inferiorly. Such changes are to be expected with the use of a tooth-borne Hyrax appliance. The line of action of the expanding Hyrax appliance is anteriorly-inferiorly positioned in relation to the center of resistance of the dentomaxillary complex.^{29,30} The use of a tooth-borne appliance that applies forces below the center of resistance, near the jugal points, causes greater widening of the inferior aspect of the maxilla than the superior aspect. Such movement, however, is readily corrected secondarily by fixed orthodontic appliances.³¹ Matteini and Mommaerts achieved greater bodily movement through the use of a bone-borne device placed high in the palatal vault between the first molars (Figure 20-4 A).^{29,30} By moving the distraction force posterior to the center of resistance in the first molar region,

greater posterior maxillary expansion is achieved. The maxillary center of resistance viewed on a lateral cephalometric radiograph is positioned on a line perpendicular to the occlusal plane located at the distal contact points of the maxillary first molars. Widening of the narrow and crowded anterior maxilla is accomplished by positioning the distraction appliance anterior to the center of resistance (canine teeth when feasible). A bone-borne appliance may be used when it is not possible to stabilize the appliance to the anterior teeth or large segmental arch wire^{30, 31} or when large bodily widening of the narrow and constricted anterior or posterior maxilla is indicated.

Anesthesia Considerations

Surgery is usually done in an ambulatory surgery setting with the patient under general nasoendotracheal anesthesia. Local anesthetic solution is injected into the depth of the labial and buccal vestibules from tuberosity to tuberosity. A long-lasting anesthetic, bupivacaine with epinephrine, provides vasoconstriction and 4 to 5 hours of postoperative analgesia.

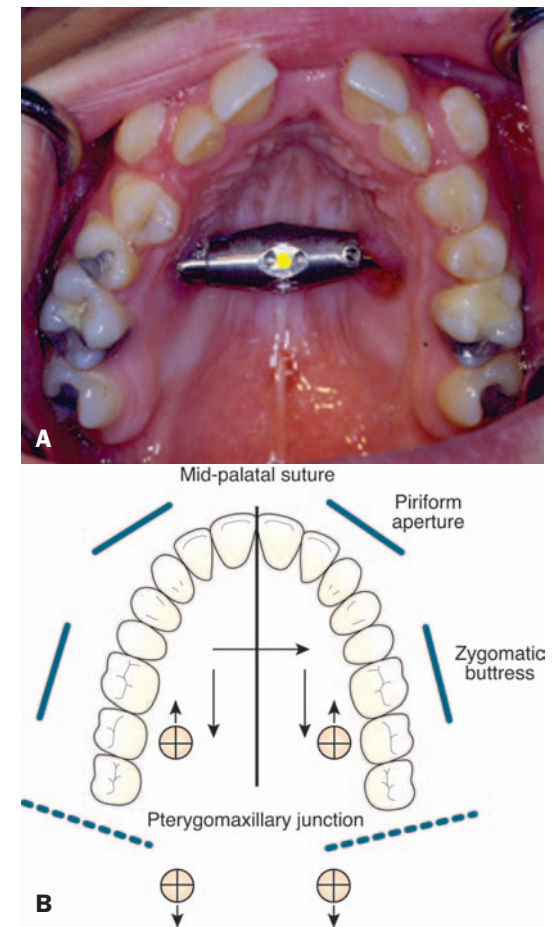


FIGURE 20-4 Bone-borne distraction appliance of Mommaerts. Positioning the distractor more posteriorly achieves a closer relationship with the distractor and the center of resistance and increases the amount of posterior maxillary expansion. The reverse applies when the distractor is positioned more anteriorly. This is the most common application of maxillary widening. The great flexibility of the bone borne appliance can achieve predictable bodily widening of the maxilla anteriorly or posteriorly because it can be readily positioned near the anteroposterior or vertical center of resistance.

Flap Design

Control of the planned vertical maxillary position is achieved by presurgical measurements (Figure 20-5). A circumvestibular incision is made with either an electrocutting or radiosurgery tip in the maxillary vestibule superior to the mucogingival junction, extending from the first molar region of one side to the first molar on the contralateral side (Figure 20-6, A and B).³² The cutting instrument divides the tissue with minimal drag, tissue distortion, or tissue necrosis and provides excellent hemostasis. Ultrasharp tungsten microneedle tips are used for precision cutting and hemostasis using low-power settings (low voltage) for intra-oral incisions (see Figure 20-6, A).³³ At the zygomatic buttress, the mucoperiosteal incision is made high in the vestibule, where the soft tissue is relatively thick and extensible. Anteriorly, the

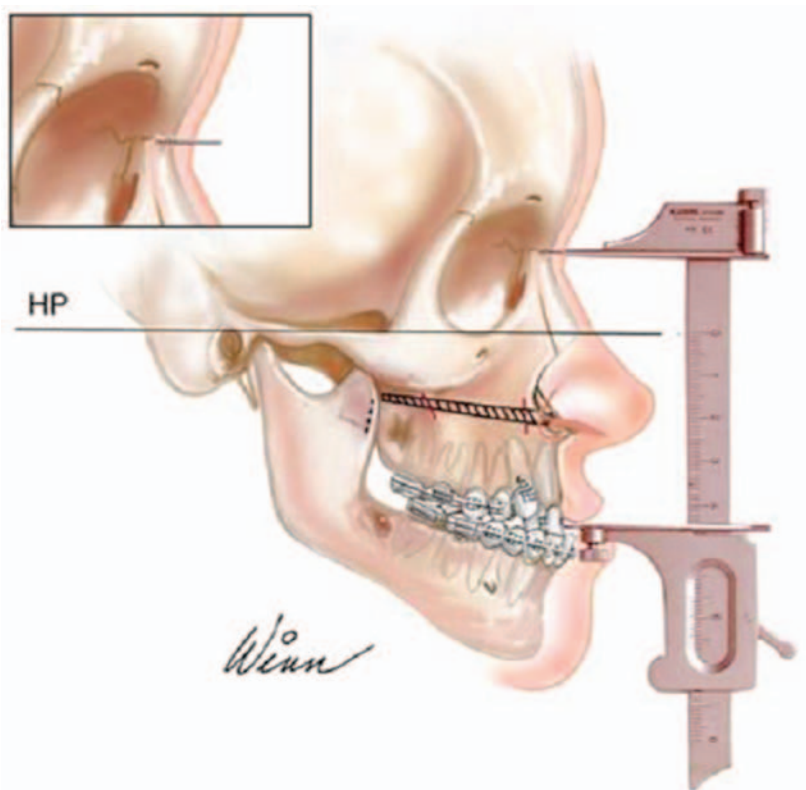


FIGURE 20-5 Monitoring vertical changes. Control of the planned vertical maxillary position is achieved by presurgical and intraoperative measurements. Following anesthesia induction, before surgery is started, an e-wire driver is used to direct a small k-wire (0.035) through the skin into the nasofrontal bony region. The length of the pin is reduced with a pin cutter so that 4 to 5 mm of pin remains exposed to serve as a measuring site. The millimetric calibrated measuring device is placed perpendicular to the natural horizontal plane (HP). The instrument can then be adapted and repositioned into a relatively repeatable measurable position. The vertical and anterior-posterior positions of the incisor teeth are measured relative to the superior edge of a bracket bonded to the central incisor tooth or incisal edge.

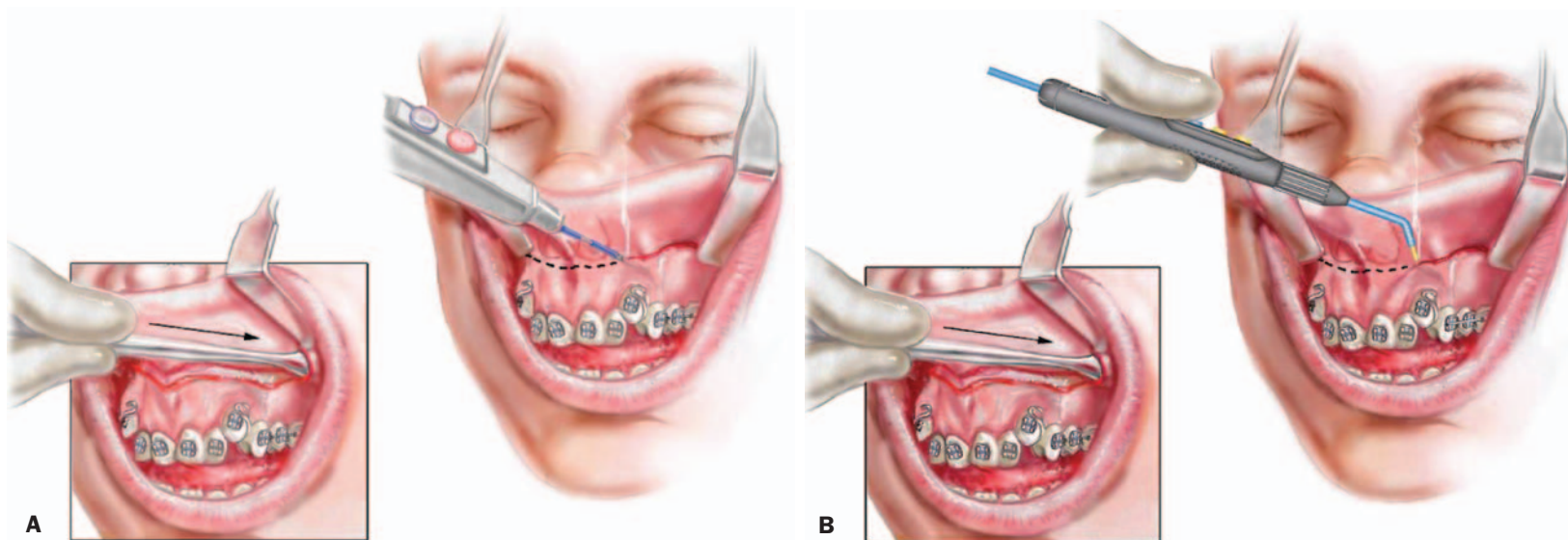


FIGURE 20-6 A, A circumvestibular incision is made with an electrocutting blade in the maxillary vestibule superior to the mucogingival junction, extending from the first molar region of one side to a similar area on the contralateral side. At the zygomatic buttress, the mucoperiosteal incision is made high in the vestibule, where the soft tissue is relatively thick and extensible. Anteriorly, the incision is made more inferiorly, 3 or 4 mm above the mucogingival junction. Electrosurgery uses electrical current as a tool to divide tissue and as a method of blood vessel coagulation to minimize tissue bleeding. The ideal cutting instrument will divide tissue with minimal drag or tissue distortion, cause minimal tissue necrosis, and provide hemostasis. Ultrasharp tungsten microneedle tips can be used for precision cutting and hemostasis using low-power settings (low voltage) for virtually all intra- and extraoral incisions (17). B, Radiowave surgery. As described by J. Niamtu in Chapter 4, radiowave surgery can be used for virtually any application for which the scalpel is used in oral and maxillofacial surgery. Indeed the Ellman frequency Surgitron has numerous advantages over conventional electrosurgery in orthognathic and cosmetic surgery. When compared with the traditional scalpel incision, electrosurgery and laser soft tissue incision and coagulation, radiowave surgery has numerous technical and practical clinical advantages, perhaps the most significant of which are simultaneous cutting and coagulation with minimal lateral tissue damage. Pressureless incisions with excellent hemostasis (see video clip) precise control, reduced postsurgical pain and faster healing are additional assets. When vascular compromise to the maxilla exists, it may necessitate the maintenance of a buccal pedicle. Through two horizontal posterior incisions, access to the nasal septum is obtained by either a vertical midline incision or a tunneling approach beneath the labial flap.

incision is made 4 or 5 mm above the mucogingival junction (Figure 20-7).

Surgical Exposure of Osteotomy Sites

The sine qua non of predictable and safe interincisal osteotomies is adequate exposure and visualization aided by excellent lighting (preferably a headlight or binocular prism loupes) of the planned interdental osteotomy site (Figure 20-8). A well-oriented radiograph is an essential part of the preoperative assessment. The incompletely ossified suture line usually seen on a periapical radiograph provides a means of identifying the planned osteotomy site intraoperatively. This is visualized through the retracted wound margins after detachment and retraction of the flap margins to expose the crestal alveolar bone (see Figure 20-8). In most patients, there is a natural divergence of the central incisor roots that precludes the need for presurgical orthodontic separation of the incisors.

The margins of the superior flap are undermined subperiosteally to expose the infraorbital nerve, infraorbital rim, anterior and lateral maxillae, zygomatic crest, and root of the zygoma (Figure 20-9). Dissection is carried anteriorly to facilitate reflection of the nasal mucoperiosteum from the lateral and inferior aspects of the piriform aperture and anterior nasal floor. The mucoperiosteum is detached from the nasal floor, base of the nasal septum, and lateral nasal walls. The inferior part of the circumvestibular incision in the maxillary midline is undermined to the crestal alveolar bone to facilitate sectioning of the

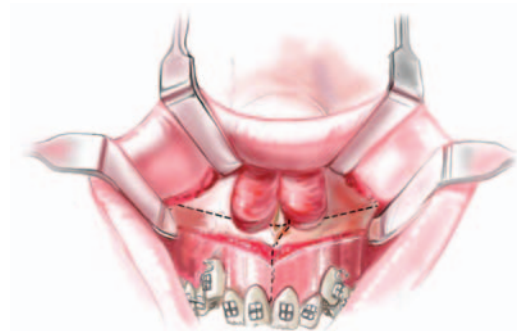


FIGURE 20-7 Incision site: Surgical technique for exposure of the anterior maxilla for the Le Fort I three-dimensional technique. A horizontal incision is placed opposite the intended interdental osteotomy site 4 to 5 mm above the level of the gingival cuff. Margins of the superior flap are undermined superiorly into the depth of the vestibule and mucosal surface of the upper lip. This provides access to the piriform aperture and floor of the nose. Broken lines indicate planned vertical interdental and lateral maxillary osteotomy sites.

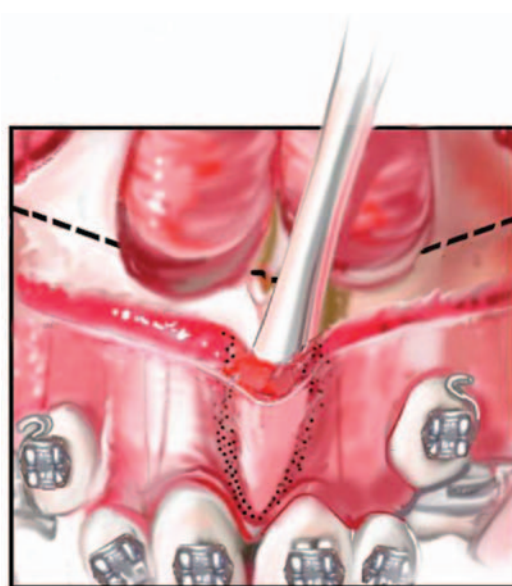


FIGURE 20-8 Visualization: Judicious subperiosteal tunneling dissection below the gingival cuff avoided the need for a vertical incision through the gingiva overlying the crestal alveolar bone. Exposure of the interdental osteotomy site between the central incisors. Stippling indicates areas of detached gingival and mucoperiosteum. Direct visualization of the osteotomized bone facilitates instrumentation of the lingual and interproximal areas, prevents excessive removal of the interdental bone, and lessens the possibility of damage to the contiguous teeth and periodontium. Great care must be exercised to maintain a palatal soft tissue pedicle to the mobilized segments.

maxillary cortical bone between the central incisors. A horizontal incision is placed opposite the intended osteotomy site 4 to 5 mm above the level of the mucogingival cuff. The margins of the superior flap are undermined into the depth of the vestibule and mucosal surface of the upper lip to provide access to the piriform aperture and floor of the nose.

Sectioning the Anterior Maxilla

The intended osteotomy is made between the central incisors to connect with the planned midpalatal and lateral maxillary osteotomies

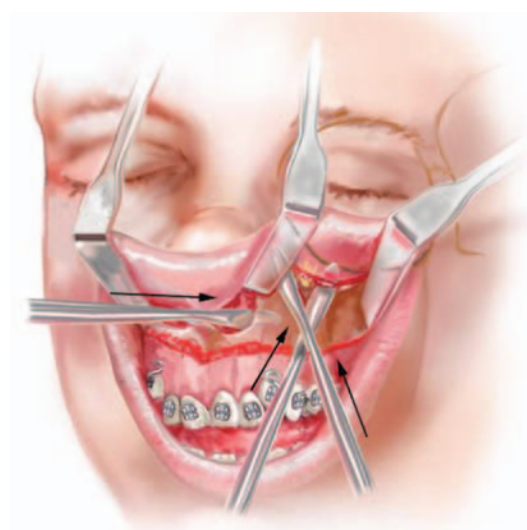


FIGURE 20-9 Exposure: The buccolabial and palatal pedicles to the mobilized anterior maxillary segment are maintained intact. The margins of the superior flap are undermined subperiosteally to expose the infraorbital nerve, infraorbital rim, anterior and lateral maxillae, zygomatic crest, and root of the zygoma. The subperiosteal tunneling is carried posteriorly to the pterygomaxillary junction and the posterolateral portion of the maxilla. Exposure of the body and the root of the zygoma is frequently made regardless of whether a high-level Le Fort I or traditional low-level Le Fort I osteotomy is planned. A broad exposure implements the high-level Le Fort I osteotomy and/or augmentation of malar bone and infraorbital areas with bone grafts or alloplasts when a traditional-level Le Fort I osteotomy is planned.

(Figure 20-10). The anterior maxilla is partially divided into two segments before the lateral maxillary osteotomies are accomplished with the margins of the mucosa retracted to visualize the labial osteotomy site. The interdental osteotomy is incompletely accomplished with a fissure bur extending from the anterior aspect of the nasal floor inferiorly to the crest of the alveolar ridge (Figure 20-11). Superiorly, the interdental osteotomy is deepened into the spongiosa; more inferiorly, the osteotomy is made through the cortical alveolar bone only (corticotomy). An interincisal osteotomy is accomplished with the reciprocating saw blade superiorly into the piriform aperture

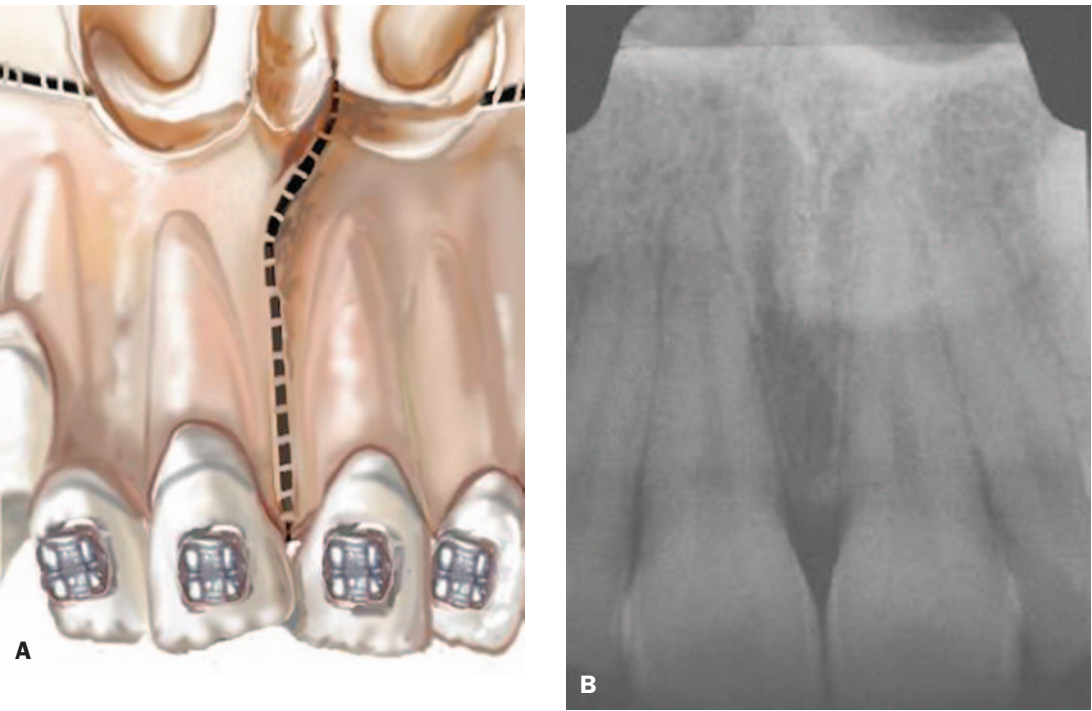


FIGURE 20-10 Interincisal osteotomy: Osteotomy is made between the central incisors to connect with the planned midpalatal and lateral maxillary osteotomies. *Dashed line* indicates planned midpalatal, interincisal, and anterior lateral maxillary osteotomy; *broken line* indicates corticotomy.

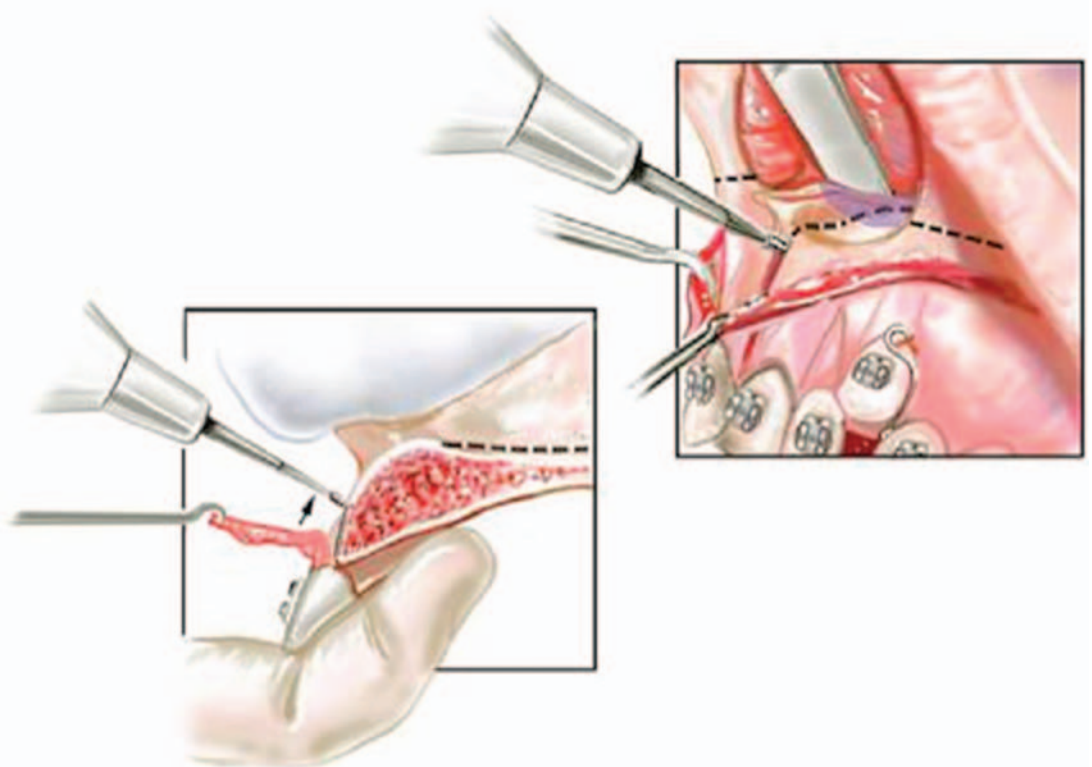


FIGURE 20-11 Sectioning: The anterior maxilla is partially divided into two segments before the lateral maxillary osteotomies are accomplished. The margins of the mucosa are retracted by small skin hooks to visualize the labial osteotomy site. The interdental osteotomy is incompletely accomplished with a fissure bur extending from the anterior aspect of the nasal floor inferiorly to the crest of the alveolar ridge. Superiorly, the interdental osteotomy is deepened into the spongiosa; more inferiorly, the osteotomy is made through the cortical alveolar bone only (corticotomy). Interincisal osteotomy is accomplished with the reciprocating saw blade superiorly into the piriform aperture; a skin hook is placed inferiorly to facilitate visualization and prevent injuring attached gingiva with the reciprocating blade.

(Figure 20-12). An osteotome is incrementally tapped into the interradicular area proceeding superoinferiorly until it partially transects the palatal bone and its tip makes contact with the nasal floor immediately lateral to the anterior nasal spine (maintained intact) (Figure 20-13). The osteotome is then malleted into the stable interseptal area between the central incisors to torque and partially fracture the crestal alveolar bone. Splitting of the anterior maxilla is facilitated by malleting and manipulating an osteotome into the center of the stable maxilla (Figure 20-14).

Individualization of the Lateral Maxillary Osteotomy Designs

When patients are operated on at an early age (12–15 years) in the presence of partially erupted, impacted, or blocked-out canine teeth or incompletely erupted second molar teeth, the lateral maxillary osteotomy is positioned at an appropriate level to avoid injury to the root apices. The measurements are varied in the canine and second molar regions based on millimetric 3-D CB CT, radiographic, cephalometric, and anatomic model surgery measurements. (See Chapter 8, “Tactile Surgical Planning Using Patient-Specific Anatomic Models.”)

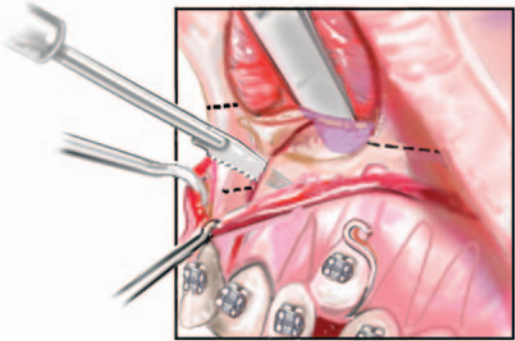


FIGURE 20-12 Interincisal osteotomy is accomplished with the reciprocating saw blade superiorly into the piriform aperture; skin hook is placed inferiorly to facilitate visualization and prevent injury of attached gingiva by reciprocating blade.

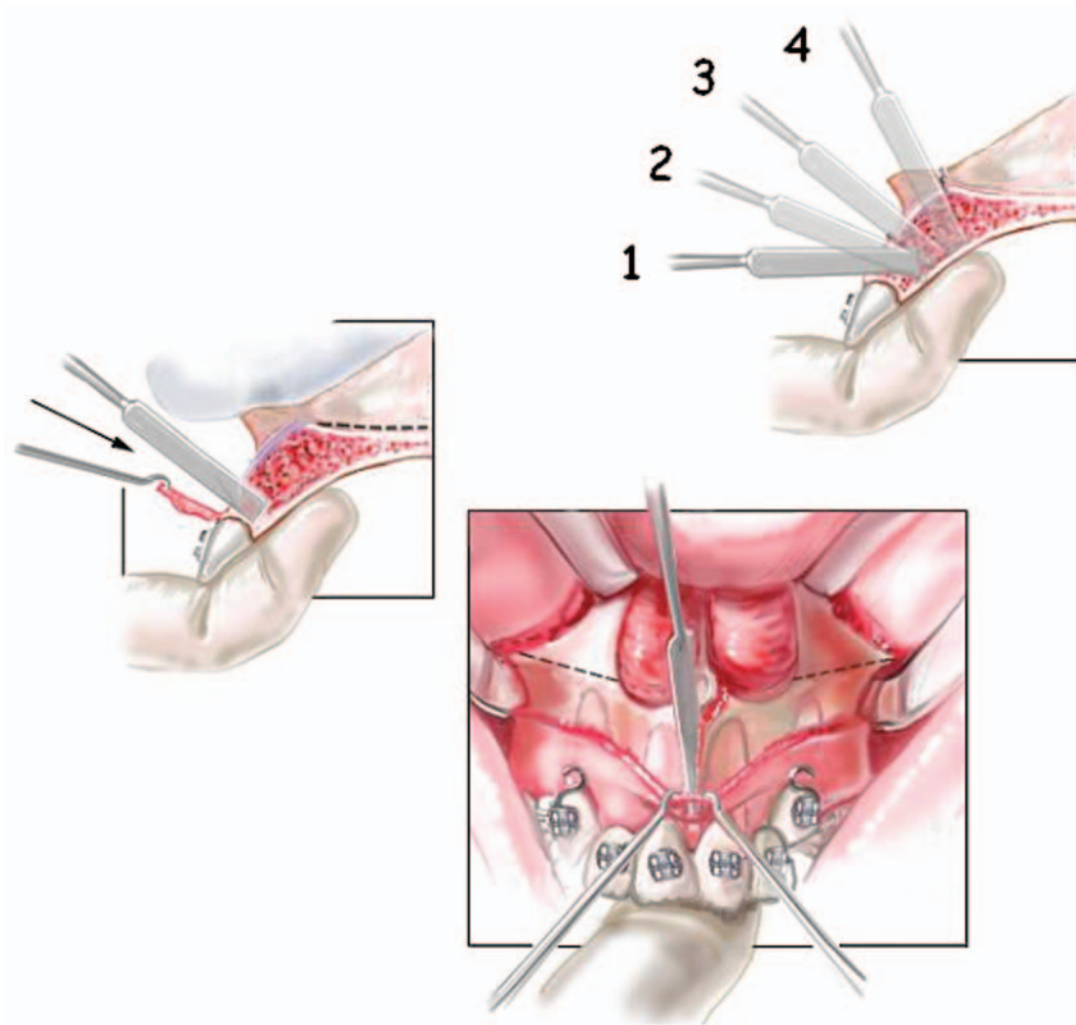


FIGURE 20-13 Sectioning: A finger is positioned on the palate to feel the reciprocating saw blade transect bone. An osteotome is sequentially malletted into the interraderic area proceeding superioinferiorly (1-4) until it partially transects the palatal bone and its tip makes contact with the nasal floor immediately lateral to the anterior nasal spine. Subperiosteal tunneling dissection of the anterior maxilla, infraorbital nerve, and anterior nasal spine. A curved Freer elevator is used to detach the mucoperiosteum from the nasal floor, base of the nasal septum, and lateral nasal walls superiorly to the base of the inferior turbinate (*stippling* on the *inset* indicates areas of detached mucoperiosteum). Given that the anterior-inferior margin of the piriform rim is usually elevated above the nasal floor, care must be taken to remain in a subperiosteal plane by dissecting inferiorly and posteriorly from the inferior piriform rim. The dissection is carried to the posterior aspect of the hard palate, onto the base of the nasal septum approximately 5 mm above the nasal floor, and then to the base of the inferior turbinate on the lateral nasal wall.

By varying the position, length, and angulation of the lateral maxillary osteotomy (Figure 20-15, A–G), a multiplicity of osteotomy designs are used to plan many of the necessary vertical and sagittal positional changes without bone

grafting.^{34–37} The geometric designs, indications, and advantages of these osteotomies differ considerably but add great versatility to the surgical technique (see Figure 20-15, A–G) and frequently may obviate the need for bone grafting and some-

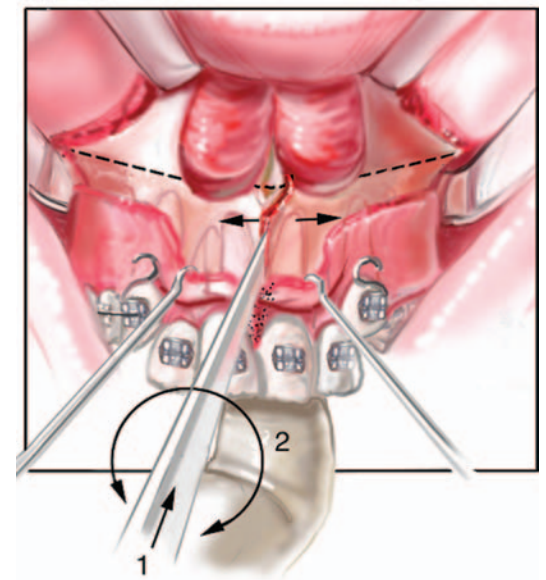


FIGURE 20-14 Mobilization: The osteotome is then malletted into the interseptal area between the central incisors to fracture the crestal alveolar bone. Digital pressure on the palatal mucosa indicates when the osteotome has transected the palatal cortex. This is important to prevent damage or detached palatal mucoperiosteum, the principal blood supply to the mobilized dental-osseous segments. Incomplete splitting of the anterior maxilla is facilitated by malleting and manipulating a sharp osteotome into the center of the stable maxilla. The two segments are made partially mobile by careful torquing and lateral manipulations of an osteotome.

times preclude the need for two-jaw surgery. Maxillary osteotomy designs are individualized based on the esthetic, cephalometric studies derived from three-dimensional cone beam distraction osteogenesis, imaging, surgical planning

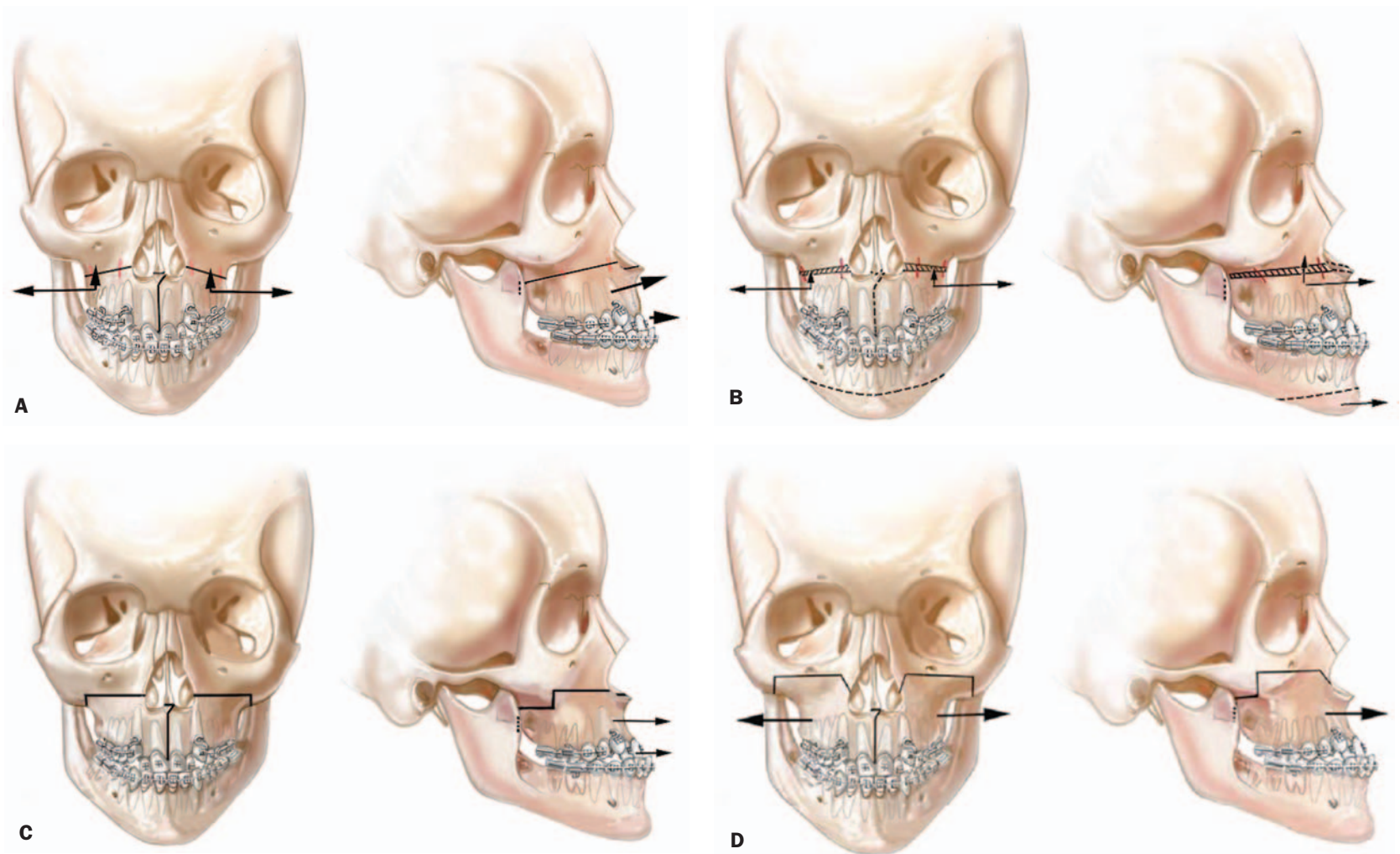


FIGURE 20-15 A, Intended osteotomy between the central incisors connects with the midpalatal and lateral maxillary osteotomies. Versatility of the three-dimensional Le Fort I/distraction osteogenesis design. Traditional low-level Le Fort I osteotomy designed to decrease lower anterior facial height as the maxilla is advanced and angled superiorly and simultaneously widened. Arrows indicate three-dimensional directional movements of the maxilla. B, Anterior-posterior and transverse maxillary deficiency associated with vertical maxillary hyperplasia: Class III malocclusion associated with crowded maxillary anterior teeth and blocked-out canines. Mandibular dentition is decompensated by presurgical orthodontics. Simultaneous three-dimensional surgical correction of the skeletal deformity by anterior-posterior, vertical, and transverse widening of the maxilla. A two-segment Le Fort I osteotomy is repositioned as a single unit, which is appropriately adjusted and stabilized in the transverse dimension by a maxillary distraction appliance. Arrows indicate three-dimensional directional movements of the maxilla. C, Lateral maxillary vertical step osteotomy designed to maintain the same lower anterior facial height when the maxilla is advanced parallel to the occlusal plane; vertical osteotomy extended into the zygomaticomaxillary buttress to provide a stable bony base because of the naturally occurring dense bone stock; the maxilla is simultaneously widened and advanced. D, High-level Le Fort I maxillary osteotomy subjacent to the infraorbital foramen designed to increase the prominence of the infraorbital, paranasal, and cheek bone areas and increase or decrease lower anterior facial height. With the use of distraction osteogenesis, multiple three-dimensional vectors of movement are frequently possible without the use of bone grafts (alternative customized distraction vectors indicated with broken lines).

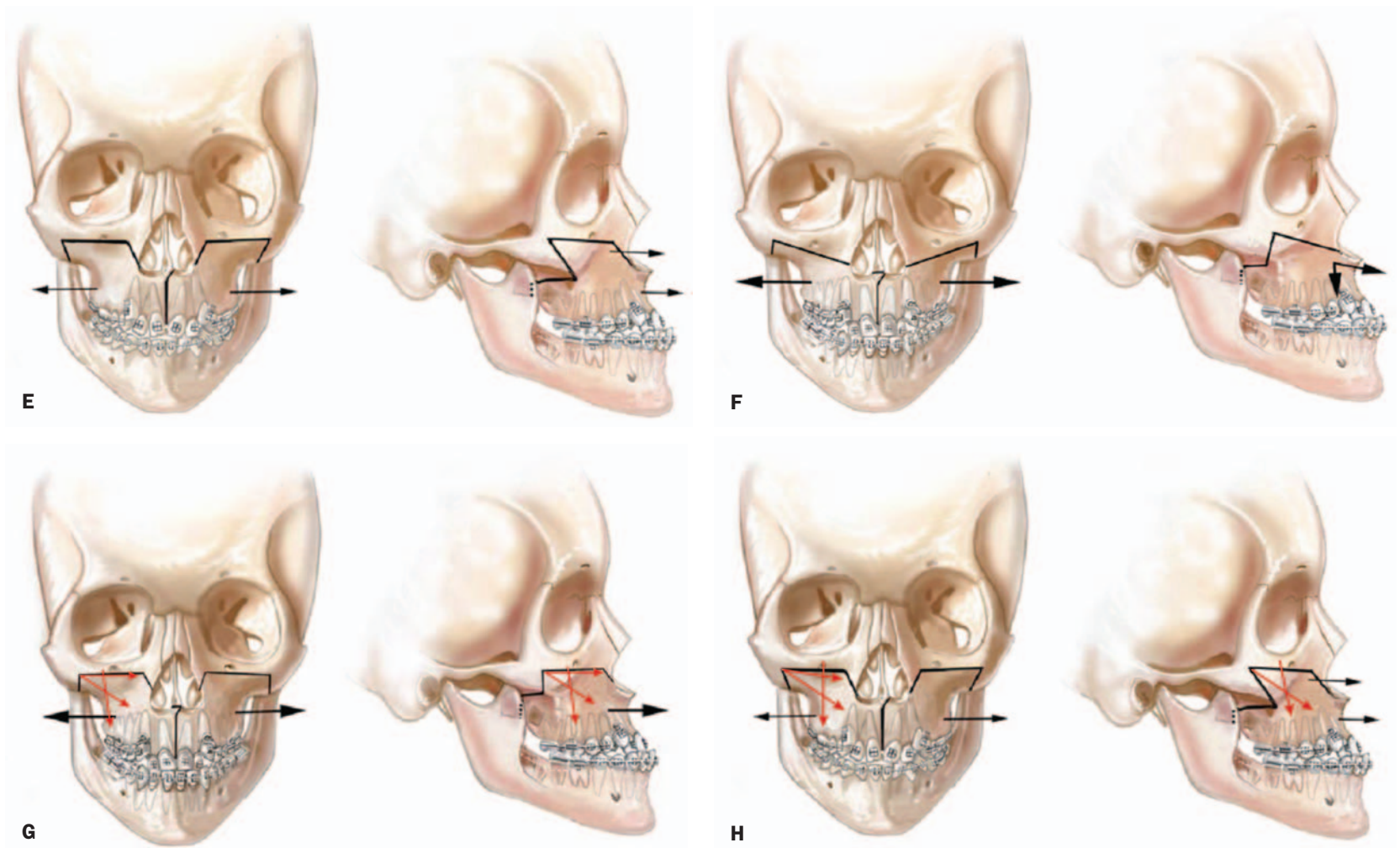


FIGURE 20-15 continued. *E*, A high-level Le Fort I osteotomy is customized to achieve variable repositioning of the maxilla to increase the vertical dimension of the maxilla, incisor exposure, and malar and lateral orbital prominence as the maxilla is repositioned (*arrows*). The lateral maxillary osteotomy courses from the piriform aperture at the level of the anterior attachment of the inferior turbinate, extending immediately inferior to the infraorbital foramen and then into the denser base of the body and root of the zygoma 5 mm or more above the inferior aspect of the zygoma. When anterior-posterior maxillary deficiency is associated with vertical maxillary deficiency, both corrections are achieved by downward and forward movements of the maxilla. Variable distraction vectors employed to achieve the desired sagittal and vertical results. High-level osteotomy subjacent to infraorbital foramen extends posteriorly zygomatic buttress to increase the prominence of the infraorbital, paranasal, and zygoma customized distraction vectors. *F*, High-level osteotomy subjacent to the infraorbital foramen extends posteriorly into the zygomatic buttress to increase the amount of incisor exposure and anterior maxillary height by downward and forward movements of the maxilla. *G*, Vertical positional change (*broken lines*). This is frequently accomplished without bone grafting. *H*, Down-ramping technique, which extends posteriorly to the zygomatic buttress; a vertical step osteotomy extends superiorly into the zygomatic buttress to increase the amount of incisor exposure and anterior maxillary height by downward and forward movements of the maxilla. Red arrows on *G* and *H* indicate optional maxillary positional changes created by altering the distraction vector.

studies, and biologic principles (Figure 20-16 A, B and C 1-7).²²

3-D LFI-DO Technique

Under general anesthesia and before the lateral maxillary osteotomies are accomplished, the anterior maxilla is partially divided into two segments (Figures 20-17 through 25). The preoperative facial analysis determines the necessary vertical maxillary repositioning, influencing the inclination of the lateral maxillary osteotomies. The Le Fort I osteotomy is then completed,



FIGURE 20-16 A, Schematic composite illustration showing the multiple sources of blood supply to the maxilla and the numerous vascular communications between the hard and soft tissues; this vascularity is the biologic reason why dento-osseous segments can be repositioned by either distraction osteogenesis or orthognathic surgery and still maintain their viability. B, Microangiogram of the second premolar region of an experimental primate animal 4 weeks after four-segment Le Fort I osteotomy to advance the maxilla 10 mm without maxillomandibular fixation. Restoration of circulation throughout bone, soft tissue, and pulp canals of the repositioned maxilla is shown. MS = maxillary sinus; NC = nasal cavity; NS = nasal septum; Pa = palatal mucosa; Pe = periodontal vascular plexus; T = maxillary first molar; Tu = turbinate. B, Schematic drawing of an experimental surgical technique. Reproduced with permission from Bell WH, Proffit WR, White RP Jr. Surgical correction of dento-facial deformities. Vol I. Philadelphia (PA): W.B. Saunders Company; 1980). C1, Maxillary occlusion before 4-piece Le Fort I osteotomy to immediately widen the maxilla 3 mm and reposition the maxilla three-dimensionally. C2, One day after immediate 3 mm widening of maxilla by 4 segment Le Fort I osteotomy; marginal gingival became detached from central incisors and was associated with vascular ischemia. C3, Early revascularization however, was followed by compromised gingival healing. Such wound healing problems do not occur with slow incremental interincisal distraction osteogenesis and histogenesis in both humans and animal studies. C4, 14 year postoperative showing stable and functional occlusion. The integrity of the gingival tissue and Interdental papilla in the esthetic zone was compromised by immediate widening of 3 mm (small black hole defect). C5, Preoperative facial appearance of a 24-year-old female with severe mandibular hypoplasia and maxillary three-dimensional deficiency. C6, Postoperative facial appearance after 10 mm mandibular advancement and genioplasty.

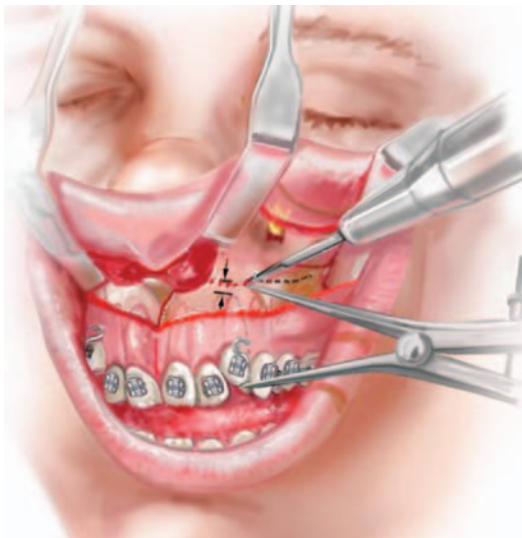


FIGURE 20-17 The location of the lateral maxillary osteotomy is determined with calipers at a level 4 to 5 mm superior to the canine and molar root apices. Vertical reference marks are inscribed into the piriform rim and zygomaticomaxillary buttress regions. Many patients are operated on at an early age (11–14 years old) in the presence of partially erupted, impacted, or blocked-out canine teeth or incompletely erupted second molar teeth. In such patients, the maxillary osteotomy is positioned at a higher level to avoid injury to the root apices. Because there is considerable variation in maxillary alveolar height, the measurements must be individualized in the canine and second molar regions based on millimetric radiographic, cephalometric, and model surgery measurements.

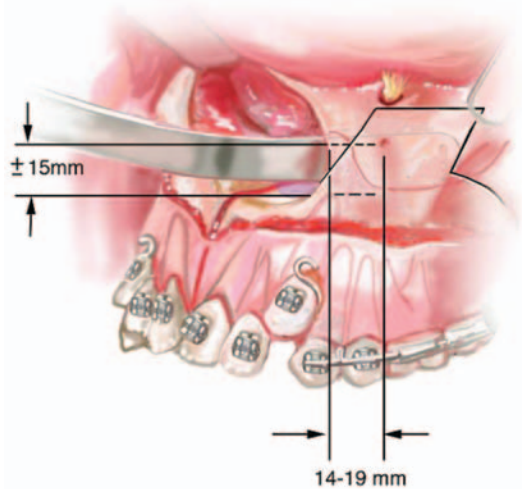


FIGURE 20-18 A Le Fort I osteotomy is frequently made above the level of the ostium of the nasolacrimal canal. Anatomic studies (20) indicate that a lateral maxillary osteotomy, made just beneath the infraorbital foramen and extended to the piriform rim at the level of the anterior attachment of the inferior turbinate (IT), will usually not injure the lacrimal duct (LD) within its bony canal. If the osteotomies of the lateral nasal wall are precisely positioned and the meatal portion of the LD is protected, the likelihood of permanent injury will be very low. The lateral nasal mucoperiosteum, containing the meatal portion of the LD, is undermined subperiosteally with a periosteal elevator up to the base of inferior turbinate to avoid injury when the osteotomy is made.

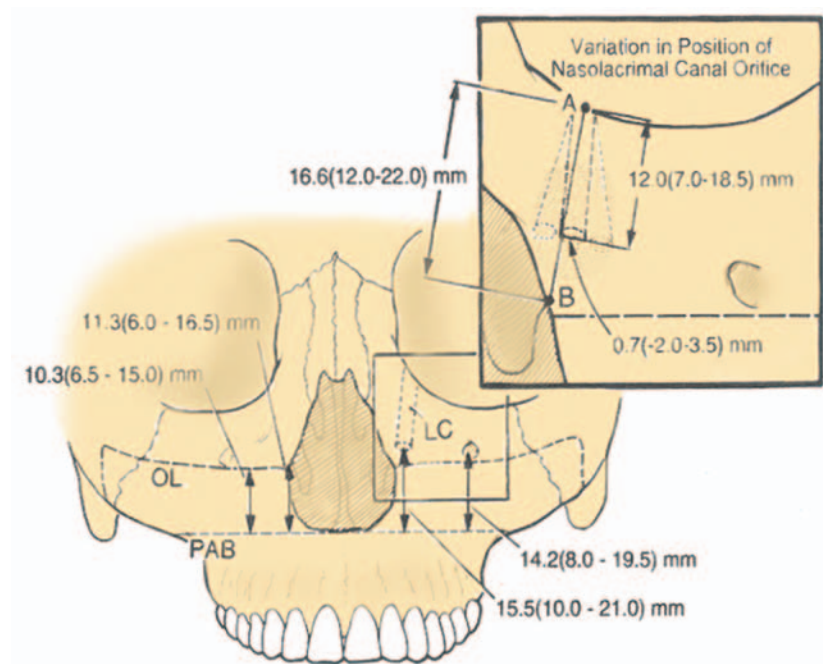


FIGURE 20-19 The illustration shows the vertical heights of the infraorbital foramen, the simulated high-level Le Fort I osteotomy, the anterior attachment of the inferior turbinate, and the inferior orifice of the nasolacrimal canal (LC) from the piriform aperture base (PAB). The insert illustrates the variation in position of the LC orifice relative to the X line, which is drawn between the lacrimal fossa (A) and the anterior attachment of the inferior turbinate (B). A line drawn between the lacrimal fossa and the anterior attachment of the inferior turbinate is a good approximation of the course of the nasolacrimal canal. OL = simulated high-level Le Fort I osteotomy.



FIGURE 20-20 The lateral and anterior maxillary walls are sectioned with a reciprocating saw blade. Anteriorly, a malleable retractor is positioned below the nasal mucoperiosteum to protect the underlying soft tissue. The remaining portion of the lateral maxilla is sectioned with the reciprocating saw blade carried posteriorly to the pterygomaxillary junction.

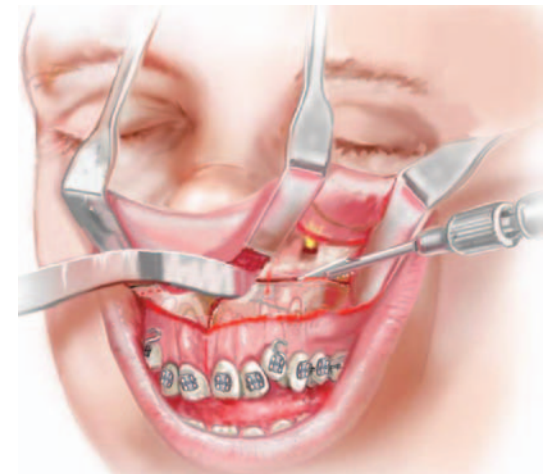


FIGURE 20-21 With the saw in a reversed position, the posterior maxillary wall is sectioned from inside the sinus to the outside, terminating at the pterygomaxillary junction. A malleable retractor is positioned to protect soft tissues attached to the lateral nasal walls. A Langenbeck retractor is positioned in the pterygomaxillary junction to facilitate visualization.

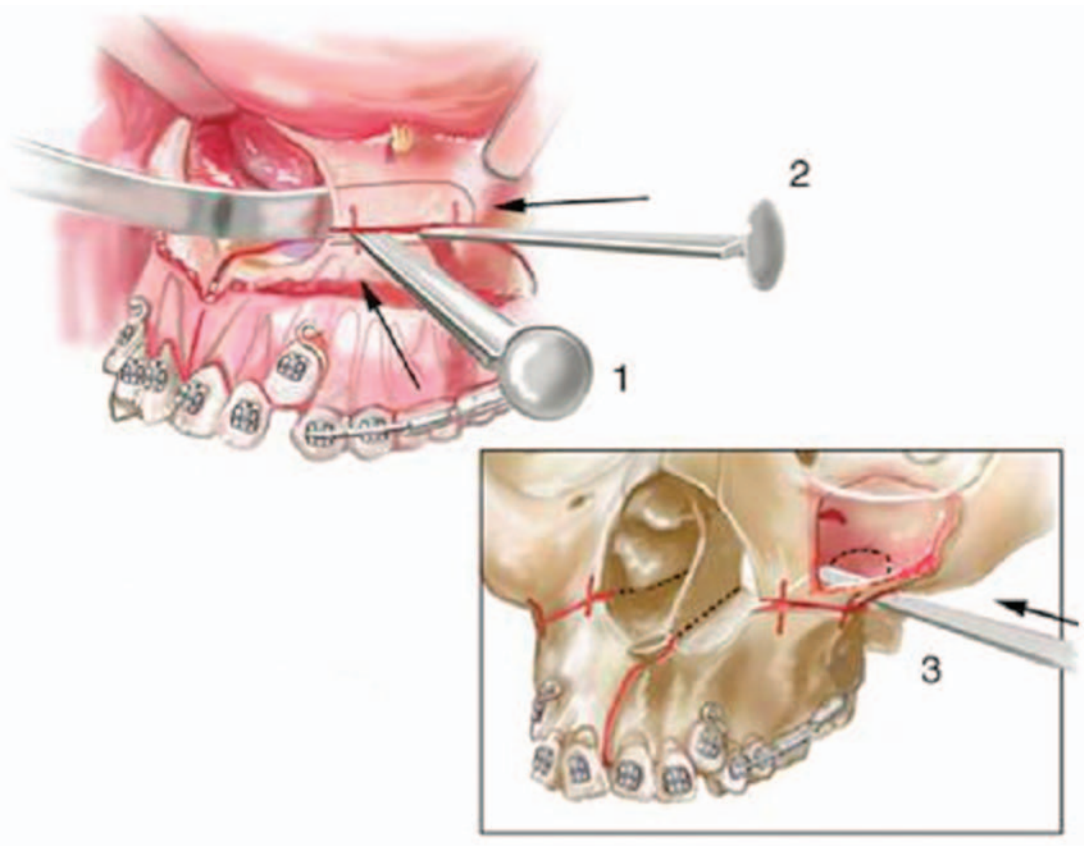


FIGURE 20-22 The medial antral wall is sectioned transorally with a fine spatula osteotome malleted through the lateral osteotomy margins. Sectioning of the medial antral wall is terminated at least 1 cm short of the perpendicular plate of the palatine bone to avoid transection of the descending palatine vessels (1, 2, and 3 indicate the sequence of sectioning). The inferior portion of the nasolacrimal duct is protected by detaching the mucosa from the lateral nasal wall and placing a malleable retractor between the mucosa and the lateral nasal wall as the osteotomy is accomplished. This procedure is particularly indicated when the Le Fort I osteotomy is made at a high level anteriorly.

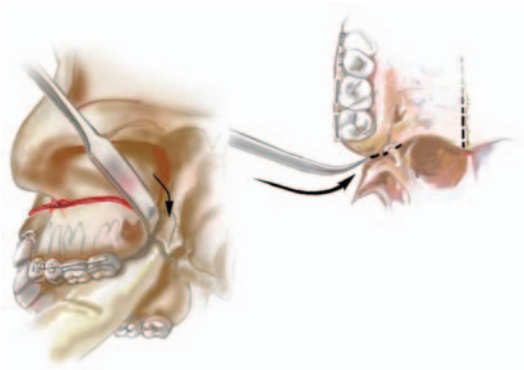


FIGURE 20-24 Pterygomaxillary disjunction. Separation of the maxilla from the pterygoid plate with a curved osteotome malleted medially and anteriorly. Proper orientation of the osteotome is achieved by placing an index finger on the palate to palpate the inferior edge of the osteotome as it transects the junction.

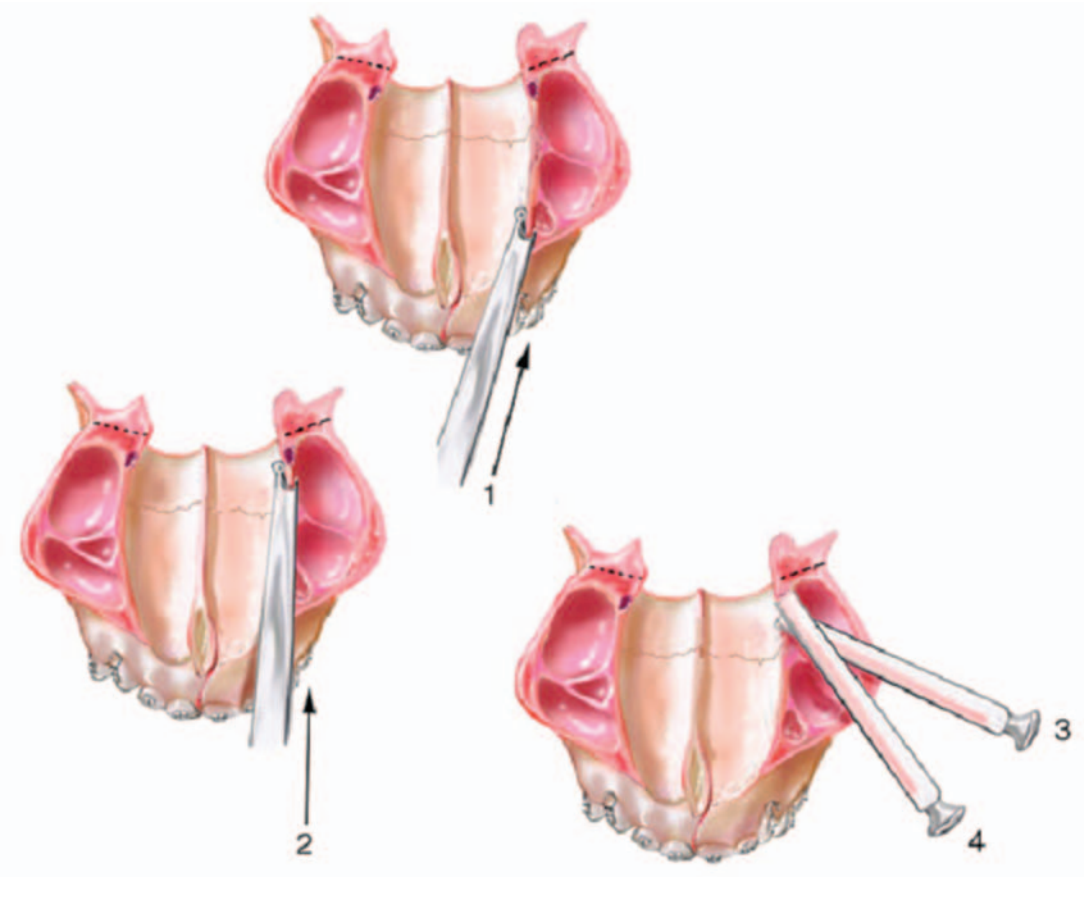


FIGURE 20-23 Optional sectioning of the lateral nasal wall. Alternative and/or adjunctive techniques: the lateral nasal wall is separated with a precisely directed spatula osteotome. Care is exercised to avoid injury to the descending palatine neurovascular bundle at the posterior part of the lateral nasal wall, which angles laterally.

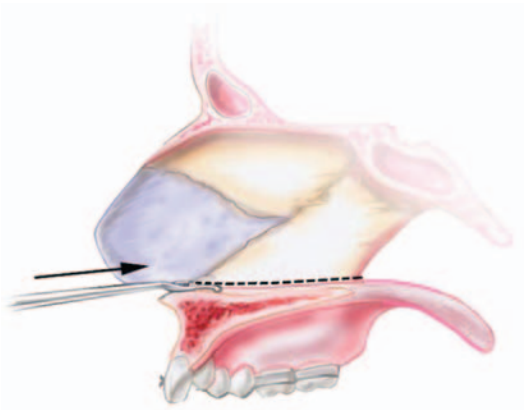


FIGURE 20-25 A nasal septal osteotome is malleted posteriorly to separate the bony and cartilaginous nasal septum and vomer from the maxilla.

(Figures 20-17 through 25) and the maxilla is downfractured (Figures 20-26A and B) and completely mobilized (Figures 20-27 and 28).

Midsagittal Sectioning of the Posterior Maxilla

Gradually increasing inferior pressure on the anterior aspect of the maxilla facilitates

visualization of the nasal surface of the maxilla and lateral nasal walls (Figure 20-26A and B). The mucoperiosteum is detached and separated from the nasal surface of the maxilla and the horizontal plate of the palatine bone to facilitate visualization, downfracturing, and complete mobility (see Figures 20-27 and 20-28). The downfractured maxilla is sectioned by a midpalatal sagittal

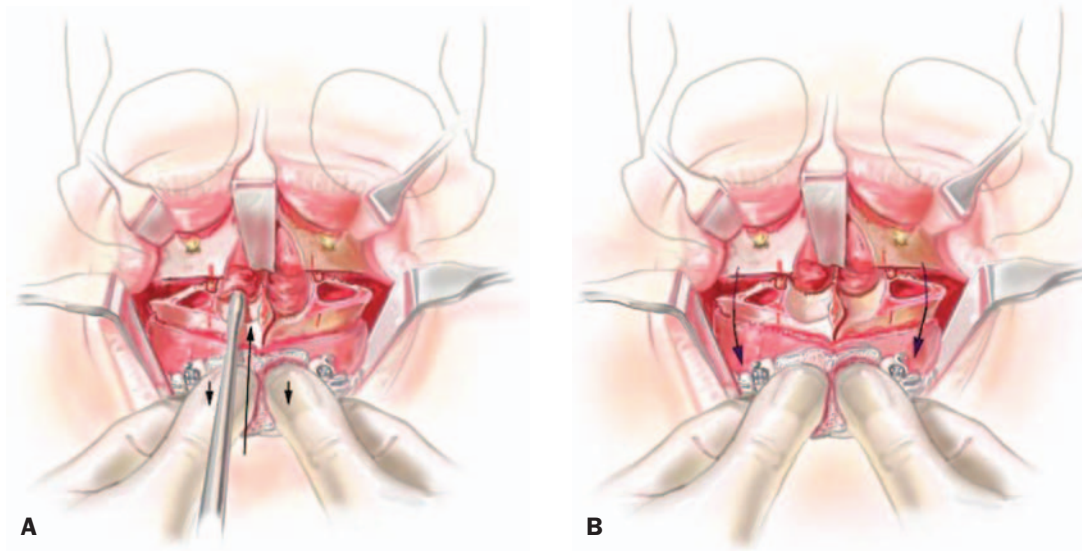


FIGURE 20-26 A, Downfracture: gradually increasing inferior pressure on the anterior aspect of the maxilla facilitates visualization of the nasal surface of the maxilla and lateral nasal walls. While the midface structures are stabilized by the assistant, the surgeon uses both hands to hinge the maxilla inferiorly and posteriorly. The assistant simultaneously detaches the remaining mucoperiosteum from the nasal floor and the horizontal plate of the palatine bone to facilitate downfracturing. B, The mobilized maxilla is hinged inferiorly on an axis that passes through the condylar heads. The remaining mucoperiosteum is detached and separated from the nasal surface of the maxilla and the horizontal plate of the palatine bone to facilitate downfracturing.

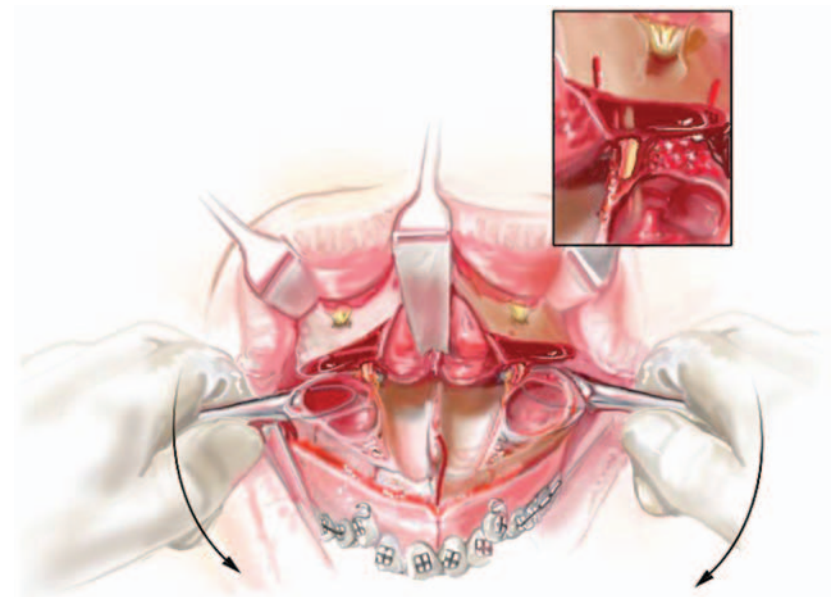


FIGURE 20-27 Mobilization of the maxilla. The descending palatine (DP) vessels are exposed; the posterior part of the maxilla is separated from its remaining bony attachment by forward pressure of a periosteal elevator or a similar instrument exerted against the thick posterior aspect of the palatine bone to achieve mobility. The Tessier hook allows full mobilization of the maxilla without injury to the palatal mucosa in cases in which total mobilization of the maxilla is difficult or not possible with the periosteal elevator. The Rowe disimpaction forceps offer another predictable means of maxillary mobilization.

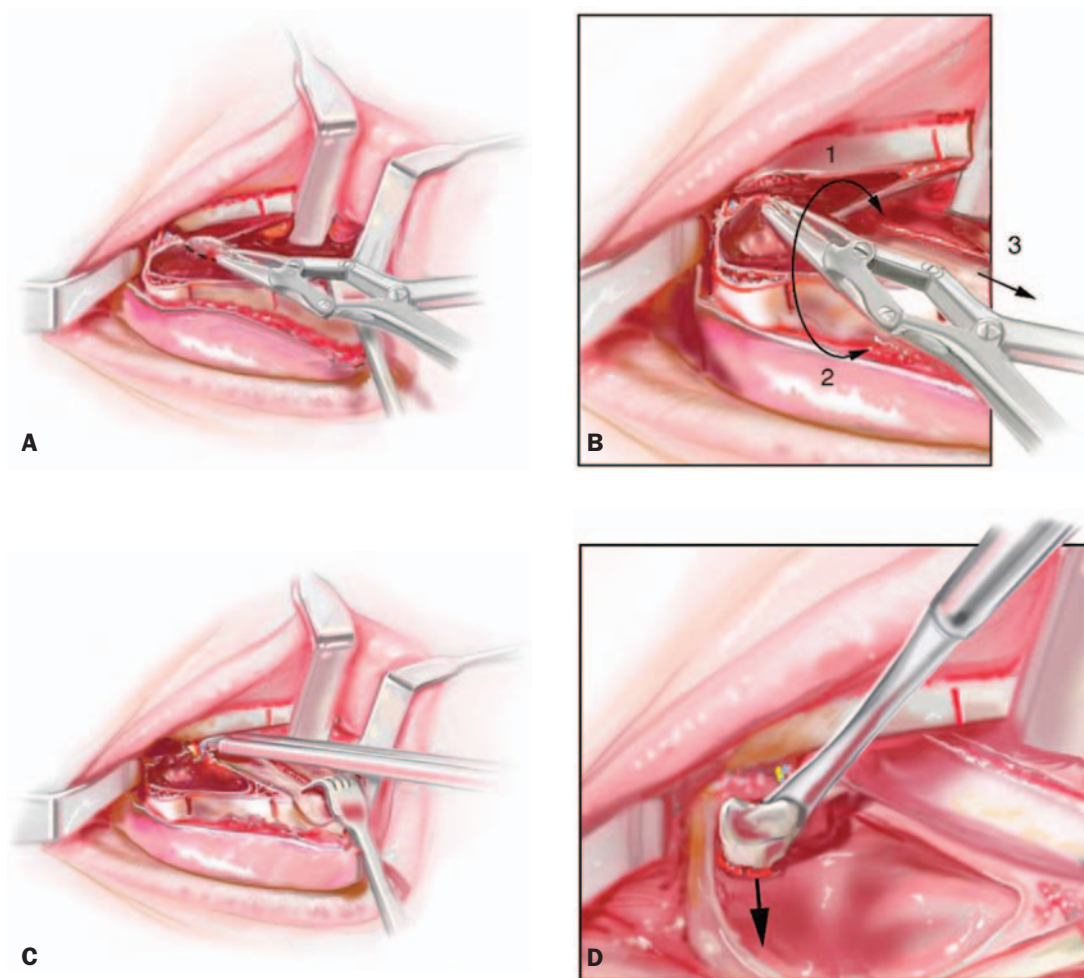


FIGURE 20-28 A and B, With the maxilla in the downfractured position, bony interferences in any area can be readily identified and removed under direct visualization. Reduction of the height of the lateral nasal walls is accomplished with rongeurs. Meticulous and sequential reduction of the posterior aspect of the lateral nasal wall and the alveolar palatal junction in the area opposite the second and third molars is accomplished with rongeurs and burs. C, Finally, osteotomes, burs, and/or Kerrison forceps are used to expose the descending palatine vessels carefully. After the overlying bone has been excised, an effort is made to preserve the integrity of these vessels whenever feasible. With large retractors positioned, the posterior maxillary tuberosity can be partially removed to facilitate superior maxillary repositioning. D, With the maxilla in the downfractured position, the bony impacted 3rd molar is readily removed with an appropriate instrument.

osteotomy accomplished with a reciprocating saw blade under direct vision (Figure 20-29). The index finger is positioned on the palatal mucosa to feel the reciprocating saw blade when it partially transects the palatal cortical plate. The bone is then completely sectioned and mobilized with an osteotome tapped gently and incrementally along the intended line of sectioning through the

thick midline palatal bone (see Figure 20-29). This osteotomy design provides the widest possible bony margins to maximize new bone regeneration by distraction osteogenesis. The relatively dense bone is covered by thin mucosa. When the maxilla is sectioned in this manner and carefully manipulated 1 to 2 mm, the palatal mucosa is maintained intact without dislodging the Hyrax

appliance or tearing the thin midpalatal mucosa. After maxillary midsagittal osteotomies, an acute activation of 1 to 2 mm is made until there is a clinically discernible separation of the maxilla (four to eight one-quarter turns of the expansion screw). The mobilized two-segment maxilla remains continuously stabilized as a single unit by the Hyrax expansion appliance (Figure 20-30).

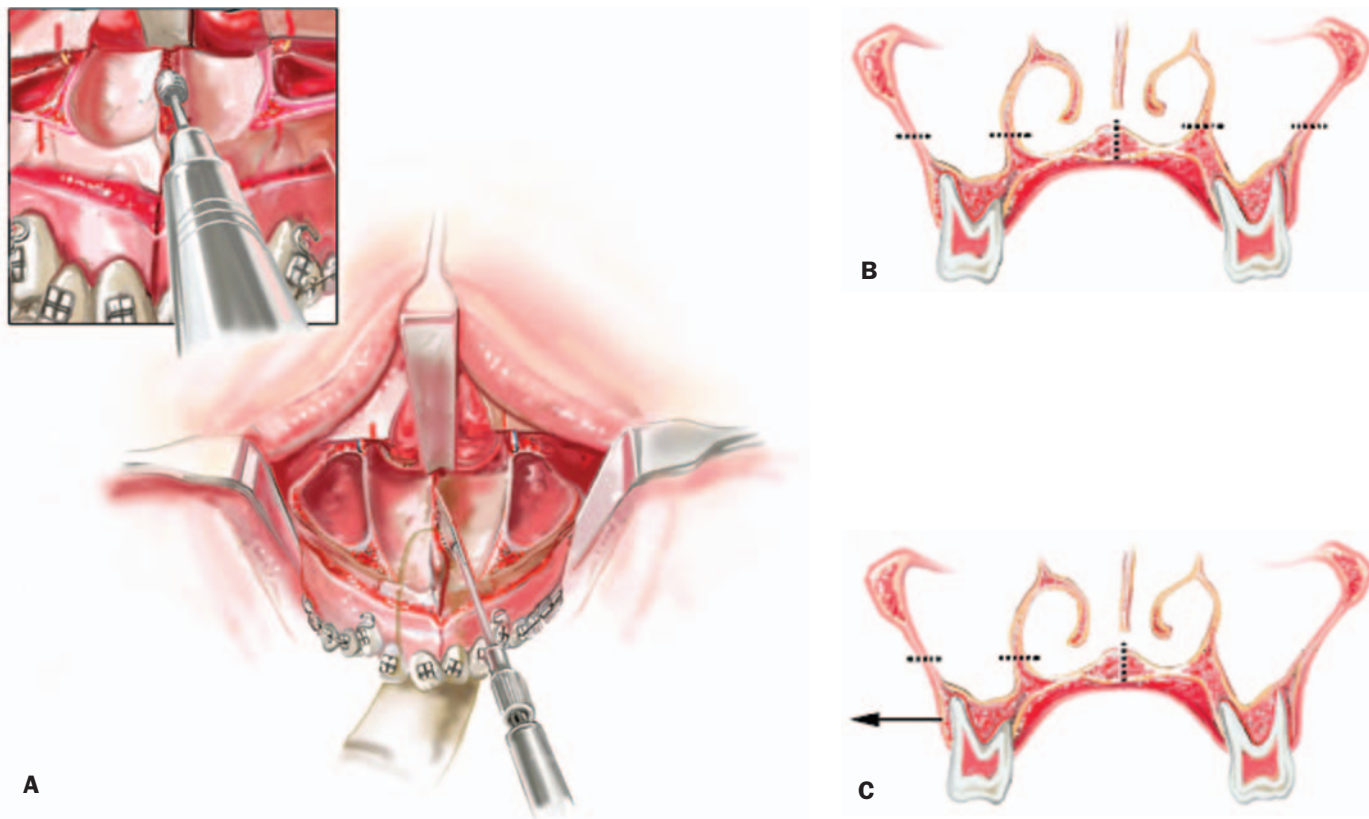


FIGURE 20-29 A, With the maxilla in the downfractured position, the posterior maxilla is widened by a midpalatal sagittal osteotomy accomplished with a straight reciprocating saw blade. An index finger is positioned on the palatal mucosa to feel the reciprocating saw blade when it partially transects the palatal cortical plates. The bone is then completely sectioned and mobilized with an osteotome malleted along the intended line of osteotomy. B, Cross section of the maxillary molar region showing the intended line of sectioning through the thick midline palatal bone; the design provides the widest possible bony margins to maximize new bone regeneration by distraction osteogenesis. This relatively dense bone is covered by thin mucosa. When the maxilla is sectioned in this manner and carefully manipulated 1 to 2 mm, the palatal mucosa is maintained intact without dislodging the Hyrax appliance. C, Alternative technique for unilateral expansion of the maxilla. Unilateral surgically assisted maxillary expansion is occasionally used in selected patients who manifest unilateral transverse hypoplasia. A vertical interincisal osteotomy is combined with midsagittal palatal sectioning and a unilateral maxillary osteotomy (anterior piriform rim posteriorly to pterygomaxillary junction). Unilateral mobilization of the hemimaxilla is achieved by fulchroming the hemimaxilla against the stable contralateral side.

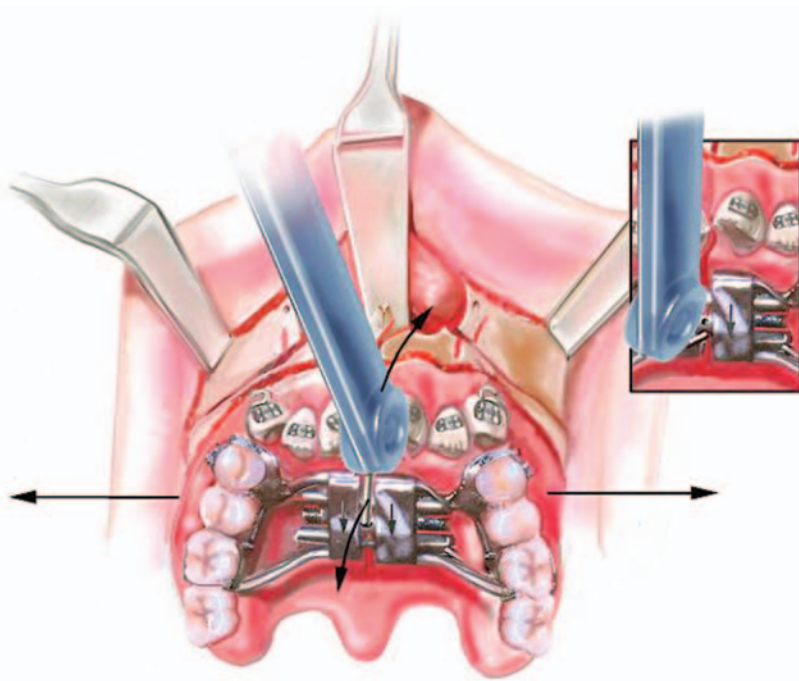


FIGURE 20-30 The expansion Hyrax device is initially activated to produce 1 to 2 mm of expansion (four to eight one-quarter turns on the expansion screw), resulting in a small distraction gap. After a latency period of 5 to 7 days, the expansion is continued at a rate of four one-quarter turns per day until the planned amount of expansion is achieved. Throughout the expansion, the surgeon carefully monitors the distraction gap to be sure of bilateral symmetric maxillary widening. When and if it becomes difficult or painful to activate the appliance, the distraction protocol is changed to two or three quarter turns each day. The patient is monitored every 2 days until the planned expansion has been achieved. When undesirable asymmetric widening is observed, the surgeon may attempt to digitally manipulate the segments or use strong cross-arch elastics. The short window of opportunity mandates immediate action to recenter the maxilla.

Positioning the Maxilla

The completely mobilized maxilla is positioned in the preplanned Class I occlusal relationship and stabilized with interdental wire ligatures (Figure 20-31). In nonextraction cases, it may not be possible to achieve a Class I canine relationship because of anterior arch length deficiency (ie, crowded anterior teeth and blocked-out canines). This is corrected after the maxilla has been widened sufficiently so that the malaligned teeth can be repositioned into the distraction gap. With the condyles positioned superiorly and anteriorly against the articular eminences, the maxillomandibular complex is rotated closed until there is anterior and posterior bony contact (see Figure 20-31). After the maxillomandibular fixation is released, with the condyles positioned superiorly against the posterior slopes of the articular eminences, the mandible is rotated closed to the planned occlusion without use of an interocclusal splint (Figure 20-32).

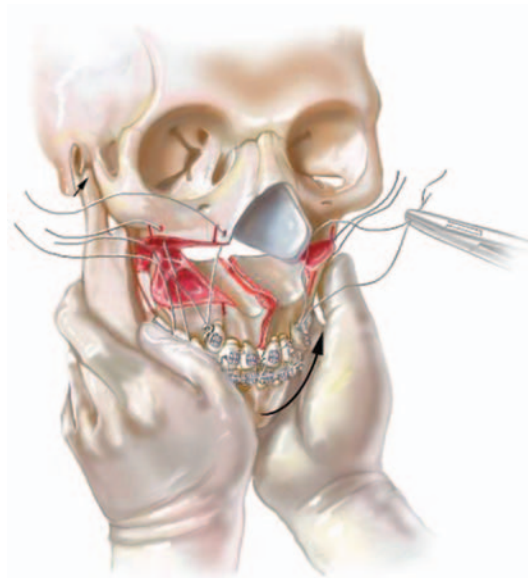


FIGURE 20-31 After the maxilla is completely mobilized, the jaws are positioned and stabilized in the planned occlusal relationship. This is usually a Class I molar. It may not be possible, however, to achieve a Class I canine relationship because of anterior arch length deficiency (ie, blocked-out or crowded canine teeth). This is corrected after the maxilla is widened sufficiently so that the malaligned teeth are repositioned into the distraction gap. With the condyles positioned superiorly and anteriorly against the articular eminences, the mandible is rotated closed until there is anterior and posterior bony contact. Finally, the maxilla is stabilized with suspension wires or thin, malleable microplates. When the mandible is to be advanced by either distraction osteogenesis or sagittal split ramus osteotomy, a guide splint can be used to index the teeth into the desired relationship. The splint is used only as a transitional guide.



FIGURE 20-32 After the maxillomandibular fixation is released with the condyles positioned superiorly against the posterior slopes of the articular eminences (*curved arrow*), the mandible is rotated closed to the planned occlusion. If there are any occlusal interferences or prematurities with the condyles seated in the desired position, the suspension wires or microplates are removed and the procedure is repeated until the planned occlusion is attained without occlusal shifting.

Stabilization Alternatives

Through the use of different combinations of bio-compatible bone plates and self-tapping screws, current techniques are more versatile than previously used methods. Straight or L-shaped mini- or microplates and screws, suspension wires, or resorbable plates and screws have been successfully used to facilitate the 3-D LFI-DO technique. The use of malleable, easy to contour mini- or microfixation plates and self-tapping screws makes these techniques easier to three-dimensionally stabilize the segment during and after distraction. They offer adequate vertical and anterior-posterior stability of the repositioned maxilla and transverse stability of the incrementally widened maxilla.

A bone plate of proper length and shape should routinely provide two holes for screws in the stable segment and two holes for fixing the

repositioned segment. The connection bar (6, 8, or 10 mm) between the inner plate holes is the site where a right-angled step is formed with a special plate-forming instrument.

Based on the planned positional changes, suspension wires (Figure 20-33A and B), thin, malleable, biocompatible straight or L-shaped

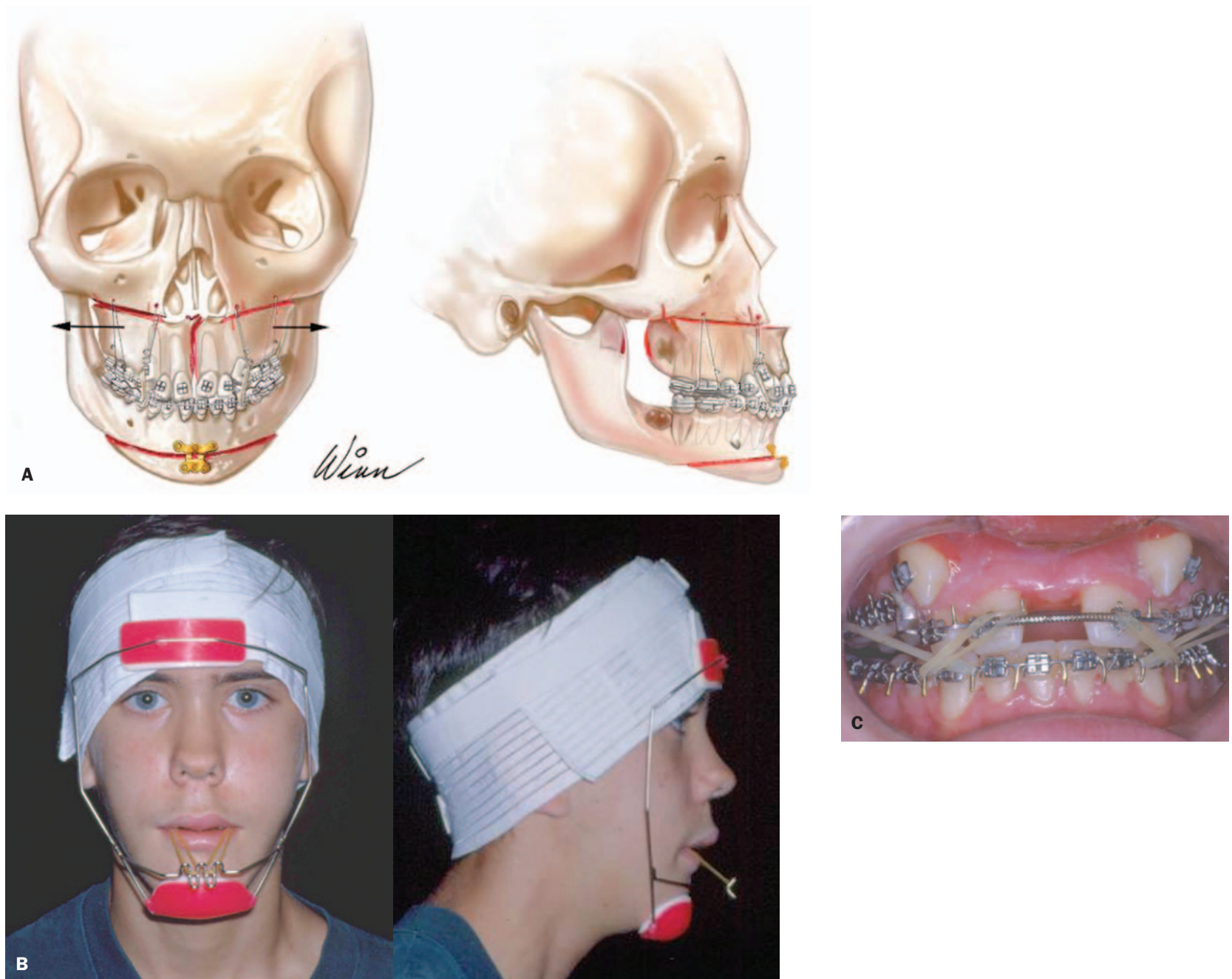


FIGURE 20-33 A, The maxilla is stabilized in Class I molar occlusion by anterior and posterior suspension wires after planned anterior-posterior and vertical positional changes are accomplished by a two-piece Le Fort I osteotomy (see Figure 20-1). A 2 mm interincisal distraction gap is created intraoperatively with a Hyrax expansion appliance; arrows indicate lateral positional changes accomplished by a maxillary distraction appliance. B, The distraction protocol includes a latency period of 5 to 7 days and a distraction rate of 1 mm per day. Positional occlusal refinement is accomplished with the use of intraoral training elastics. A facial mask is employed occasionally to provide continuous heavy force to the maxilla to achieve the intended distraction vector and planned positional change. The facial mask is secured to the face by stretching elastics from the hooks on the maxillary splint to the crossbow of the facial mask. Heavy forces are generated through the use of 14 oz elastics, which are used in concert with training elastics to achieve the desired occlusal refinement during the short postsurgical window of opportunity (2–3 weeks). C, The maxilla stabilized in preplanned occlusal relationship after 8 mm widening by distraction osteogenesis; distraction regenerate is present between central incisors. After the planned amount of widening has been attained, the segments are stabilized to prevent the incisor teeth from moving into the empty distraction gap (“walking teeth”). This is accomplished with small stabilizing wires or a prosthetic appliance (preferred when dental esthetics is a priority). Periapical radiographs are taken at weekly intervals to assess the gradually increasing radiodensity of the distraction regenerate. The first radiographic evidence of new bone formation is usually noted between 3 and 4 weeks after surgery. Increasing radiographic density of the distraction regenerate provides a guideline as to when orthodontic treatment should be started. Approximately 6 weeks after surgery, active orthodontic closure of the distraction gap is undertaken. Leveling and alignment are accomplished with an appropriate flexible orthodontic wire. The distraction appliance is maintained in place 6 to 8 weeks after the planned amount of expansion has been achieved to allow consolidation of the transverse stability.

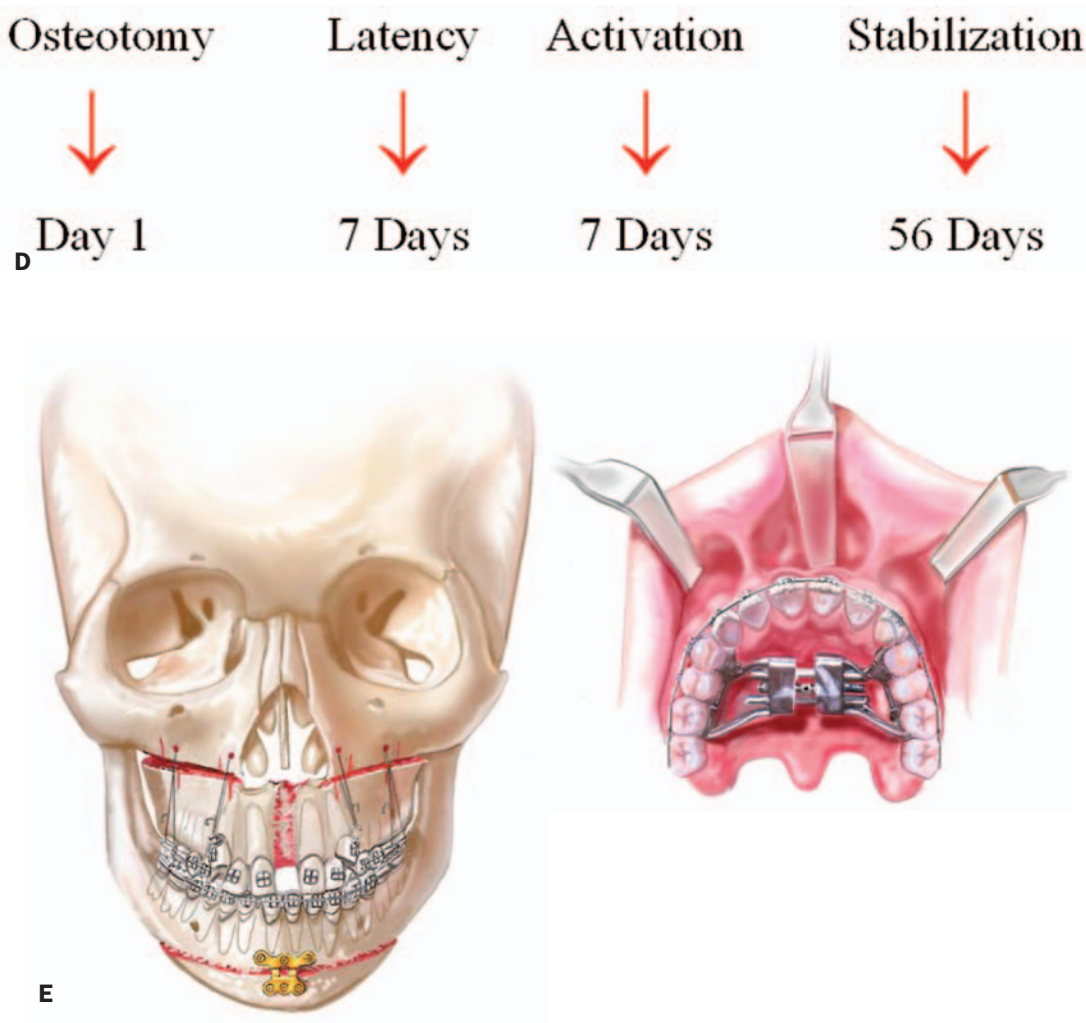


FIGURE 20-33 continued. *D*, Distraction osteogenesis protocol for maxillary widening. *E*, The distraction gap is maintained for 6 to 8 weeks after the planned amount of expansion is achieved to allow consolidation and enhanced transverse stability. Six weeks after surgery, active orthodontic closure of the distraction gap is undertaken with an appropriate and flexible light orthodontic wire. The malaligned teeth are orthodontically repositioned into the distraction gap. The Hyrax appliance serves as an excellent skeletal retainer during the consolidation period.

microplates (Figure 20-34), and self-drilling bone screws may be used to facilitate stabilization without the use of interocclusal splints.^{38,39} Microplates require minimal bending and trial fitting to the underlying bone (see Figure 20-34). The plates are contoured with light digital pressure so that they rest passively against the bone surfaces. The plates are secured to both the distal and proximal segments with 1.7 mm self-drilling positional screws. The suspension wires (see Figure 20-33C) or malleable microplates (see Figure 20-34) offer minimal resistance to lateral maxillary expansion by the Hyrax appliance. The use of malleable, easy to contour suspension wires or microfixation plates and self-drilling screws in concert with the Hyrax appliance makes these techniques easy to stabilize the segments during and after distraction.³⁹ (They provide adequate vertical and sagittal stability of the repositioned maxilla while allowing slow incremental maxillary widening by distraction.) The two-segment maxilla united and stabilized by the Hyrax appliance is easily repositioned and manipulated as a stable “one-piece” maxilla. A bone plate of proper length and shape provides two holes for screws in the stable

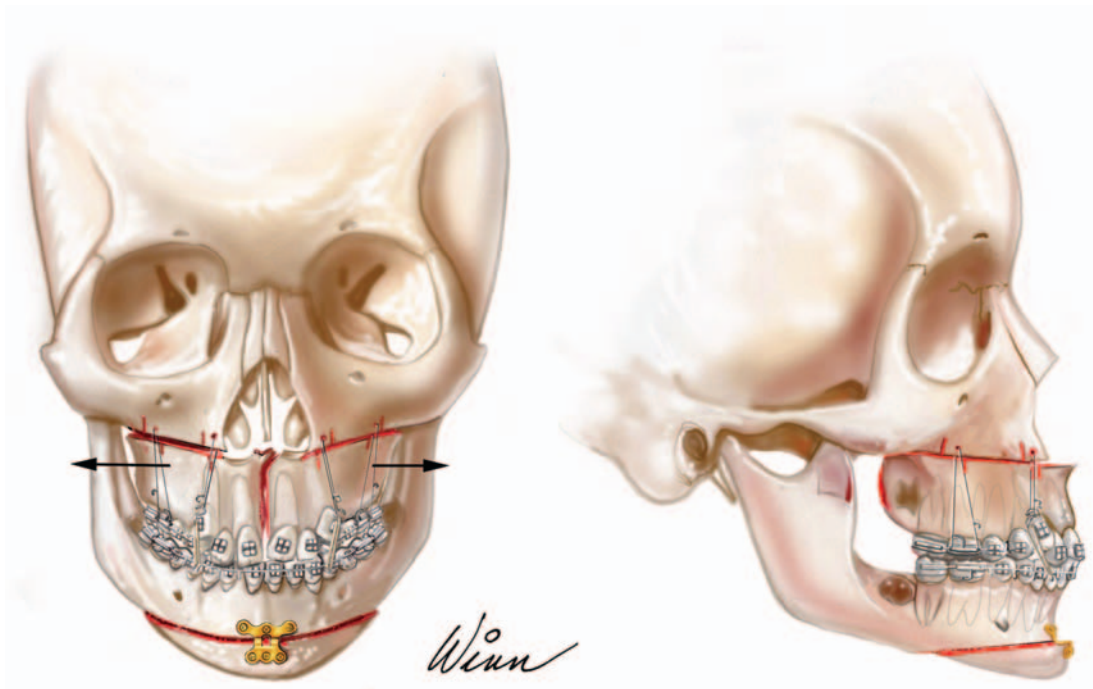


FIGURE 20-34 The maxilla is stabilized in Class I molar occlusion by anterior and posterior microplates after planned anterior-posterior and vertical positional changes are accomplished by a two-piece Le Fort I osteotomy. A 2 mm interincisal distraction gap is created intraoperatively with a Hyrax expansion appliance; arrows indicate lateral positional changes accomplished by a maxillary distraction appliance.

segment and two holes for fixing the repositioned segment. It is important to maintain a speed lower than 1,000 rpm and to irrigate the drill to minimize thermal damage to the bone. Because screw pullout strength is directly related to cortical bone thickness and screw size, bone screws are placed in the thickest available bone stock.

Technical Modifications

Prebent straight titanium four-hole miniplates with interconnecting bars or malleable resorbable plates³⁸ and screws are used occasionally to facilitate immediate repositioning of the maxilla (Figure 20-35A).³⁹ Plates are secured with self-drilling bicortical 1.5 mm-diameter bone screws of variable lengths to facilitate anterior-posterior and vertical repositioning of the maxilla. Widening of the superior bony margins is achieved intraoperatively with a periosteal elevator or similar instrument (Figure 20-35, B). Widening at the occlusal level, however, is

accomplished incrementally with the Hyrax appliance by distraction osteogenesis after the latency period. For instance, if the treatment plan calls for widening the maxilla 10 mm, a 4 to 5 mm step is formed in the connecting bar portion of both miniplates (Figure 20-35C). The dual action of a bone-forming instrument facilitates bending the plate at the connecting bar (6, 8, or 10 mm) between the inner plate holes to form a 90° step. The combined length of the steps on both sides is equal to the amount of the desired maxillary expansion (determined from analysis of the arch width). Plates are usually placed anteriorly and posteriorly in the densest available bone stock.

Window of Opportunity for Occlusal Refinement

The distraction protocol includes a latency period of 5 to 7 days at a distraction rate of 1 mm per day. Positional occlusal refinement is accomplished

with the use of intraoral training elastics. When necessary, a facial mask is employed to provide continuous heavy force to the maxilla to achieve the intended distraction vector and planned positional change (see Figure 20-33B). The mask is secured to the face by stretching elastics from the hooks on the maxillary splint to the crossbow of the facial mask. Heavy forces are generated through the use of 14 oz elastics, which are used in concert with training elastics to achieve the desired occlusal refinement during the short post-surgical window of opportunity (2–3 weeks) (Figure 20-33D).

Maxillary Expansion

The Hyrax distraction appliance is activated 5–7 days postoperatively (latency period) at a rate of 1.0 mm/d until the planned expansion is achieved (see Figure 20-33D). After distraction is completed, the appliances are stabilized for the following 6 to 7 weeks (consolidation period),

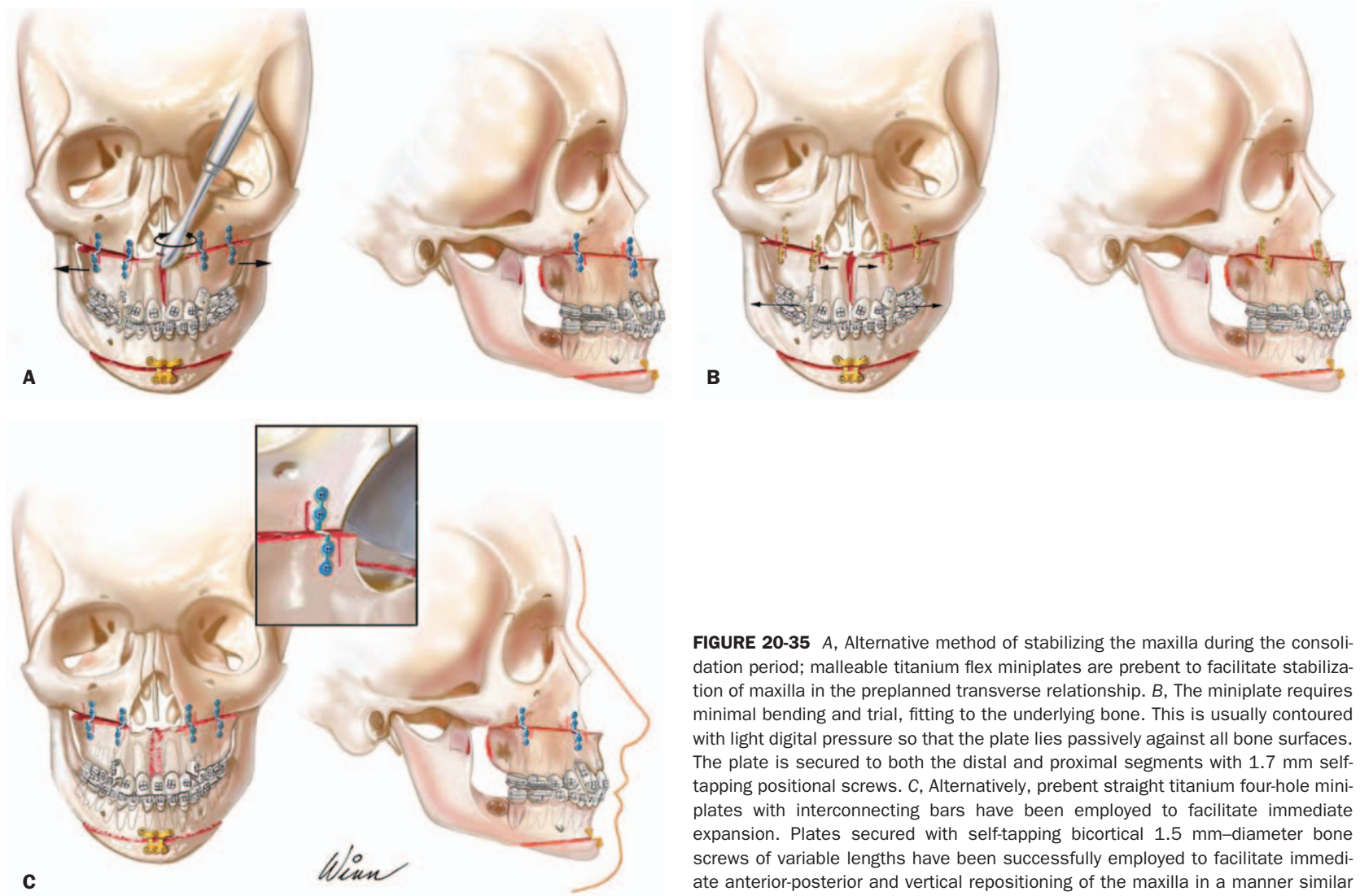


FIGURE 20-35 A, Alternative method of stabilizing the maxilla during the consolidation period; malleable titanium flex miniplates are prebent to facilitate stabilization of maxilla in the preplanned transverse relationship. B, The miniplate requires minimal bending and trial, fitting to the underlying bone. This is usually contoured with light digital pressure so that the plate lies passively against all bone surfaces. The plate is secured to both the distal and proximal segments with 1.7 mm self-tapping positional screws. C, Alternatively, prebent straight titanium four-hole miniplates with interconnecting bars have been employed to facilitate immediate expansion. Plates secured with self-tapping bicortical 1.5 mm-diameter bone screws of variable lengths have been successfully employed to facilitate immediate anterior-posterior and vertical repositioning of the maxilla in a manner similar to that used with orthognathic surgery.

at which time the incisors are orthodontically repositioned into the distraction regenerate with a light archwire.

If there is evidence of vascular ischemia or detachment of the gingiva from the underlying bone, the activation is immediately terminated; the distractor is reversed and stabilized for 7 to 8 days. In clinical practice this has not been necessary during or after distraction. By contrast, however, such problems are predicted when den-toalveolar segments are immediately repositioned in excess of 2 or 3 mm. When there is pain associated with appliance activation, the daily activation schedule is modified to 0.5 mm every 12 hours. The consolidation period varies with the magnitude of movement and the patient's age. It is the surgeon's responsibility to precisely monitor distraction and consult with the orthodontist when necessary.

The patient is seen as often as necessary to achieve the preplanned bilateral symmetric maxillary expansion. If undesirable asymmetric widening is observed, the segments can be digitally manipulated or crossarch elastics are used to center the maxilla. The short window of opportunity mandates immediate action and meticulous monitoring.

Consolidation Period

After the planned amount of widening is achieved, the segments are stabilized to prevent the incisors from moving into the distraction gap ("walking teeth") (see Figure 20-33C and D).^{20,28} This is accomplished with small stabilizing wires or a dental prosthesis (preferred when dental esthetics is a priority). Periapical radiographs are taken at weekly intervals to assess the gradually increasing radiodensity of the distraction regenerate. The first radiographic evidence of new bone formation is usually noted between 3 and 4 weeks after surgery. Increasing radiographic density of the distraction regenerate provides a guideline as to when orthodontic treatment can be started.²⁵ Approximately 6 weeks after surgery, active orthodontic closure of the distraction gap is undertaken with an appropriate flexible light orthodontic wire (see Figure 20-33C through E). The distraction appliance is maintained in place for 6 to 7 weeks after the planned amount of expansion is achieved to allow consolidation and enhanced transverse stability.

Surgical Outcomes and Discussion

Once we had passed the "learning curve," our operative times dramatically decreased and occlusal results have improved significantly. Most of our recent cases have been operated on in 1 to 1½ hours, depending on the number and complexity of the procedures accomplished. Patients are usually released from the ambulatory surgery

center on the same day of surgery. Sagittal and vertical positional changes of the downfractured mobilized maxilla are accomplished by individualized lateral maxillary osteotomies. Simultaneously, the maxilla is widened by distraction osteogenesis. Maxillary widening at the central incisor level has ranged from 5 to 14 mm. Le Fort I osteotomy and distraction osteogenesis provide an efficient method of widening the maxilla, straightening malaligned teeth, creating space for the eruption of impacted or blocked-out canines, and achieving the desired vertical and sagittal positional changes with or without extractions. Movement of teeth into the bony regenerate and concomitant orthodontic treatment resolve dental crowding (see Figure 20-3). To date, there have been no soft tissue, osseous, or dental infections. Fibrous unions or nonunions of the repositioned bone segments have not been observed. Additionally, soft tissue or papilla loss has not been observed.

The surgical technique may be combined with other adjunctive esthetic procedures in a wide variety of three-dimensional maxillary deformity patients (Figure 20-36). Genioplasty, submental liposuction, rhinoplasty, malar augmentation, and otoplasty may add significantly to the overall psychosocial benefits of treatment. Impacted teeth are surgically removed from the downfractured maxilla (see Figure 20-28D), a few from a high buccal flap. To date, none of the patients have experienced alveolar osteitis. This is probably related to the patient's age at the time of surgery, the osseous architecture, and the simplicity of the surgery (see Figure 20-28D).

There have been minimal differences in the probing depths of the maxillary midline surgical site when compared with the adjacent interproximal areas of the same patient. Damage to the periodontal hard and soft tissues in the vertical interdental osteotomy sites is also minimal when compared with the adjacent interproximal areas. Virtually no differences in the gingival or papilla architecture or alveolar bone levels are discernible when compared with adjacent interproximal sites.²⁵ There have been no surgical infections, fibrous unions, nonunions, and/or radiographic or clinical evidence of papilla loss or blunting in the anterior maxillary esthetic zone (Figure 20-36A–E).

Variable root resorption after orthodontic mechanotherapy is a reality for most orthodontic specialists. The duration of treatment, bone density, significant torquing, and vulnerability of specific teeth to the resorption process (central incisors) are the most important factors predisposing the patient to root resorption (see Figure 20-3 and 20-36).⁴⁰ To date, minimal root injury or resorption has been discernible on the postoperative periapical radiographs of the teeth repositioned into the distraction gap.²⁵ Further studies

are indicated to determine the long-term effect of tooth movement into the distraction gap. The results suggest that repositioning teeth into the distraction regenerate has a sparing effect on the roots of the repositioned incisor teeth (see Figure 20-3 and 20-36).

The current study involved a predominantly adolescent and young adult population manifesting transverse maxillary deficiency and other variable vertical and sagittal disharmonies. Previous studies have shown that vertical maxillary growth continues after Le Fort I surgery in adolescent patients. In this study, patients had minimal anterior maxillary growth after comparable surgery, which would be expected of similarly aged untreated patients.⁴¹ Discernible occlusal change, temporomandibular joint dysfunction, and facial disproportionality have not been observed over the postoperative follow-up period. Proportional growth observed over a 7-year follow-up period preserves the facial appearance postsurgically and gives support to the use of relatively early surgery in selected adolescents to three-dimensionally reposition the maxilla (see Figure 20-36A).

In this group of patients, interdental widths increased significantly anteriorly and posteriorly. Maxillary widening at the central incisor level ranged from 5 to 14 mm. New bone formation between the central incisors is usually noted between 3 and 4 weeks after surgery.²⁵ Follow-up radiographs (periapical and posterior-anterior) show transverse repositioning of the distracted maxilla and new bone bridging the distraction gap. Predictable three-dimensional repositioning of the maxilla by our technique is predicated on the mobility of the maxilla at the time of downfracture, although there are other reported techniques that do not employ complete mobility.

The maxilla is selectively lengthened and vertically repositioned by variable lateral maxillary osteotomy designs to alter the vertical and sagittal dimensions of the repositioned maxilla (see Figure 20-15). Maxillary widening is achieved slowly by incremental distraction osteogenesis and histiogenesis without injury or tearing of the palatal mucosa, with minimal gingival or crestal alveolar bone injury, and with minimal discernible root resorption.

Controlled studies are indicated to compare the long-term stability of tooth-borne versus bone-borne maxillary widening techniques. Tooth-borne appliances have been implicated as the cause of loss of anchorage, periodontal membrane compression, loss of papilla, root resorption, cortical fenestration, and skeletal relapse during and after the expansion period. To date, none of these problems have been discernible with the use of our 3-D LFI-DO technique, which is contingent on complete mobility of the maxilla.



FIGURE 20-36 A and B, A 12 year-old female was initially seen for surgical orthodontic treatment of her anterior open bite. Her facial growth was judged to be incomplete. Diagnosis: vertical maxillary excess and transverse maxillary deficiency, mandibular anterior-posterior deficiency; microgenia, Class II anterior open bite, severe crowding of maxillary anterior teeth, and four impacted third molar teeth. Facial appearance pretreatment (age 12 years); facial proportionality 3 years later (age 15 years); 6 years after treatment (age 19 years); Class II anterior open bite (age 12 years) before treatment; Class I occlusion 3 and (1) 6 years after treatment. There was an insignificant difference in probing depths of the surgical site compared with interproximal areas before and after surgery. Treatment plan: three-dimensional Le Fort I/distracted osteogenesis to reposition sagittally and vertically and widen the maxilla 9 mm; mandibular advancement; advancement genioplasty; extraction of four impacted third molar teeth.



FIGURE 20-36 continued. C, 3-D dentofacial deformity with Class I malocclusion, crowded and malaligned maxillary and mandibular anterior teeth and lower left bony impacted canine. Arrow points to deciduous canine tooth. Maxillary and mandibular dentitions partially decompensated by presurgical orthodontics. Simultaneous 3-D surgical correction by widening of the maxilla and mandible 9 mm each to create space for impacted and blocked-out canine tooth and increase arch width. C1, pre operative occlusion – center, C2, preoperative occlusion – left, C3, preoperative occlusion – right, C4, pre operative panoramic view of lower left complete bony impacted canine tooth with no space between the adjacent lateral incisors and first molar. C5, post operative occlusion, C6, post operative occlusion – front, C7, post operative occlusion – left, C8 Post operative panoramic view of lower left canine tooth positioned normally in the dental arch.

Limitations of the Technique

Maxillary osteotomy designs are individualized based on esthetic, cephalometric, and surgical planning studies and skeletal anatomy. When the amount of vertical, sagittal, and transverse repositioning exceeds the movement possible by customizing the lateral maxillary osteotomy design, distraction osteogenesis, accomplished with two distractors, offers an alternative to bone grafting. In selected cases, repositioning may be accomplished with the use of a second labial buccal distraction appliance in concert with a palatal expansion appliance.

Before surgery, the distraction appliances are measured, cut, and preshaped based on clinical, computerized planning software (*Nemotec*), cephalometric prediction, and three-dimensional CT scans. A uniplanar stainless steel intraoral osteo distractor (Dynaform, Stryker Leibinger Inc., Kalamazoo, MI) consists of a central body connected to four flexible arms (Figure 20-37A). The flexible arms are reduced in length the amount necessary to precisely position the distractor. The contour of the device is modified by digital manipulation against a stereolithographic model. The body of the appliance contains a 12 mm threaded rod. O-rings and fork-ends are attached to the terminal ends of each arm by way

of a cutter crimper device. The O-ring and/or fork-end configurations of the terminal ends engage the positional bone screws used to stabilize the distal and proximal bone ends (Figure 20-37B).

After the maxillomalar complex to be repositioned is mobilized, the distractor is precisely placed in the preplanned position and stabilized by (2 mm diameter, 8–10 long) unicortical positional screws placed through the O-rings or fork-end devices (see Figure 20-37). A trocar can be used to place the screws transcutaneously. A specially designed right-angled screwdriver may also be beneficial for placing the screws transorally. (See Chapter 54, “Contra-Angle Technique for Rigid Fixation of the Sagittal Split Ramus Osteotomy.”) The anterior part of the distraction appliance is fixed transorally with bicortical screws (Figure 20-37C). The position and orientation of the distraction rod determines the appropriate repositioning vector. Acute separation of the margins (1–2 mm) of the segment to be repositioned is carefully assessed. After a latency period of 5 to 7 days, the distractors are activated 1 mm per day until the preplanned positional change is achieved. The customized distal maxillary segment is repositioned anteriorly and inferiorly during activation (Figure 20-37D).

The incremental positional changes are continually monitored and compared with the preoperative distraction vector plan and occlusal changes. Vertical positional changes are assessed and monitored through the use of a nasofrontal reference marker (generally, an overcorrection of 20%). If the occlusion at the end of distraction does not correlate with the planned movement (open bite, dental asymmetry), the circumdental wires or stabilizing screws are removed under local anesthesia. Training elastics are placed between the maxillary and mandibular vertical lugs previously bonded to the archwires. The necessary occlusal changes are usually observed overnight (frequently within minutes). After monitoring and achieving the desired occlusion, the stabilizing bone screws and/or circumdental wires are replaced to fixate the maxilla in the corrected position. The corrected occlusion is continuously monitored during the consolidation period, usually without the use of an interocclusal splint. Planning treatment for mandibular excess entails diagnostic consideration of all three dimensions of space if optimal results are to be obtained with contemporary surgical and orthodontic techniques. Mandibular excess may be described generally as prominence of the lower third of the face. Such actual (absolute)

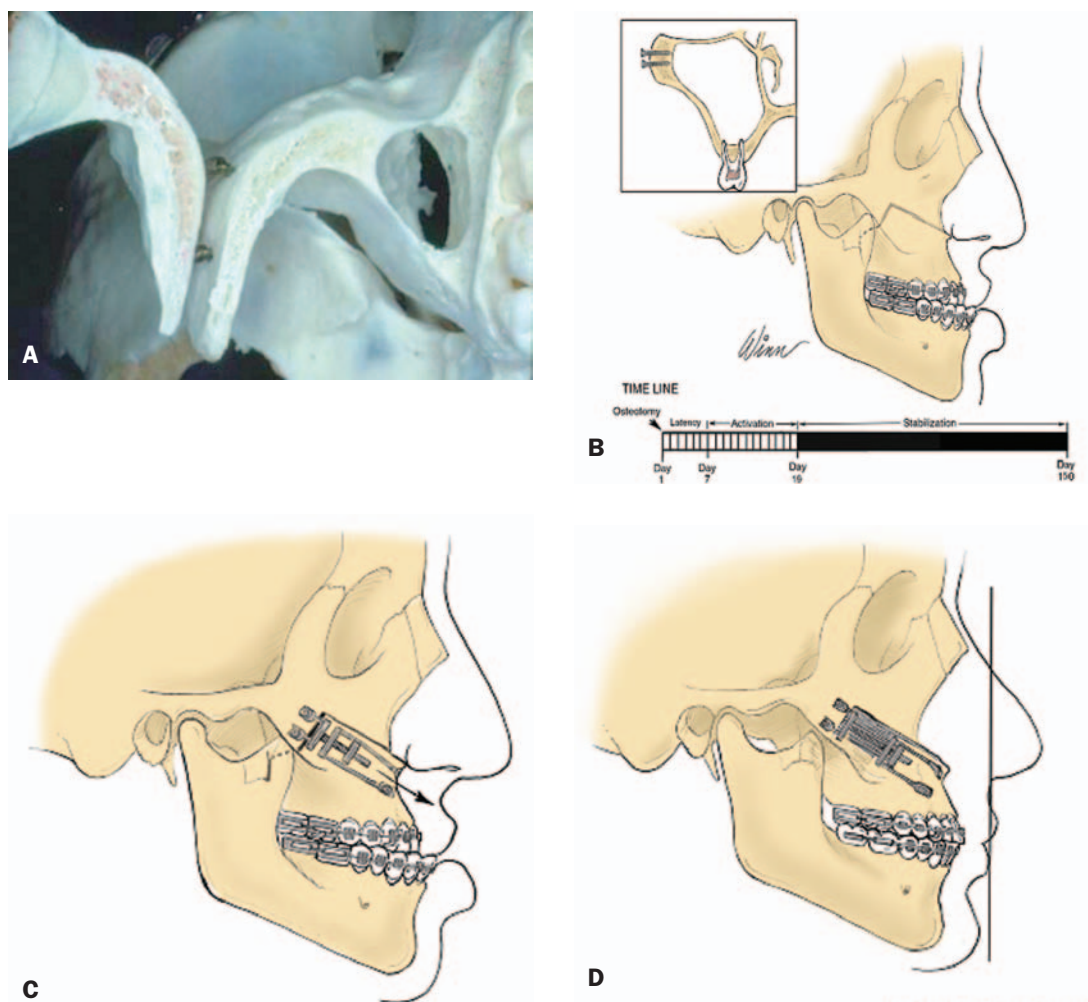


FIGURE 20-37 Uniplanar maxillary osteodistraction technique: A, Axial view demonstrates the abundant bone stock present in the zygomatic buttress which is typically used to stabilize the proximal part of the osteodistractor with positional screws. Notice the very thin anterior wall of the maxilla. B, Variably positioned vectors (arrows) control the positional change of the maxilla. C, Maxillary osteodistraction vector directional change controlled by the angulation of the distraction rod. Anterior part of osteodistractor stabilized by positional screws and/or circumdental wires. D, Distractor is activated intraoperatively sufficiently to test the vector of movement; the distraction rod remains lengthened 1-2 mm during the latency period. As maxilla is lengthened anteroinferiorly it remains stabilized by positional screws placed through the O-rings or fork-ends appliances. Distraction regenerate gradually forms between the proximal and distal segments.

prominence must be differentiated from other (relative) conditions in which the lower facial third appears prominent anteroposteriorly because of a midfacial deficiency. The patient with severe vertical maxillary deficiency and, therefore, proportionally less anterior facial height, may appear to have severe mandibular prognathism when, indeed, the essentially normal-sized mandible is rotated upward and forward into a relatively prognathic relationship (Figure 20-38 A-G). Treatment planning for correction in all three planes of space, therefore, will require inclusion of inferior repositioning of the maxilla when the vertical maxillary deficiency is severe.

Case Report I

This case describes correction of severe transverse vertical and mild sagittal maxillary deficiency and

transverse maxillary deficiency associated with relative mandibular excess by simultaneous repositioning of the maxilla and mandible by maxillary distraction, osteogenesis and sagittal split ramus osteotomies. The use of computerized planning software (*Nemotec*), 3-D CB CT, reconstruction imaging and surgical navigation may be used to simulate jaw movement and associated soft tissue changes.

During the distraction period, the distal segment is repositioned inferiorly and slightly anteriorly, causing an increase in the lower anterior facial height and a decrease in chin prominence (see Figure 20-38E). Despite careful planning, there may be a small discrepancy between the actual and planned distraction vector. The altered orientation of the distraction appliance (distraction osteogenesis rod) (see Figure 20-38) may produce a small anterior open bite during maxillary lengthening. Success with secondary

repositioning of the maxilla is dependent on manipulating the distraction callus before the fibrous interzone ossifies. Radiographic analysis of the distraction gap at the end of the distraction period and at the beginning of the consolidation period typically shows a central radiolucent fibrous interzone surrounded by newly formed bone trabeculae emanating from the edges of the distracted segments. At this stage, the interzone is occupied by extensible collagen fibers. The shape of the distraction regenerate can be changed by anterior traction or by digital manipulation of the mechanically weak callus. A very small discrepancy between the planned and actual distraction vector can have a significant effect on the final occlusion (see Figure 20-38). Immediate action rapidly corrects these problems and refines the occlusion. Secondary repositioning to achieve a more desirable occlusion is accomplished under local anesthesia. Through the use of elastic traction to the maxillary and mandibular orthodontic lugs the maxilla is rapidly repositioned into the desired occlusion. (see Figure 20-38).

The technique described in this chapter is not for everyone. Patient compliance, surgeon availability during the distraction period, orthognathic surgical skills, knowledge of fundamental distraction osteogenesis wound healing and biomechanical principles, meticulous treatment planning, and prudent clinical judgment are mandatory for success. Without these, it is easier and more prudent to use other surgical alternatives, such as premolar extractions in concert with surgically assisted maxillary expansion in one or two stages or traditional three- or four-segment LeFort I osteotomy with indicated orthognathic surgery. In such cases, the same biologic and clinical distraction osteogenesis principles are applied to correct the three-dimensional skeletal disharmony.

In the future, computerized planning software, three-dimensional virtual imaging, and surgical navigation will be used routinely to simulate maxillary and mandibular surgical movement and associated soft tissue changes. With the development of such high technology and computer programs to simulate three-dimensional positional changes of the maxilla,^{26,42,43} simultaneous correction of three-dimensional maxillary deformity by the 3-D LFI-DO will be one of many alternative techniques used in the paradigm shift in orthognathic surgery. This surgery will be done more rapidly, and affordably in convenient ambulatory surgical center.

Case Report II

Another patient, a 15-year-old student, sought treatment to decrease the prominence of her maxillary incisors, improve her smile line, increase

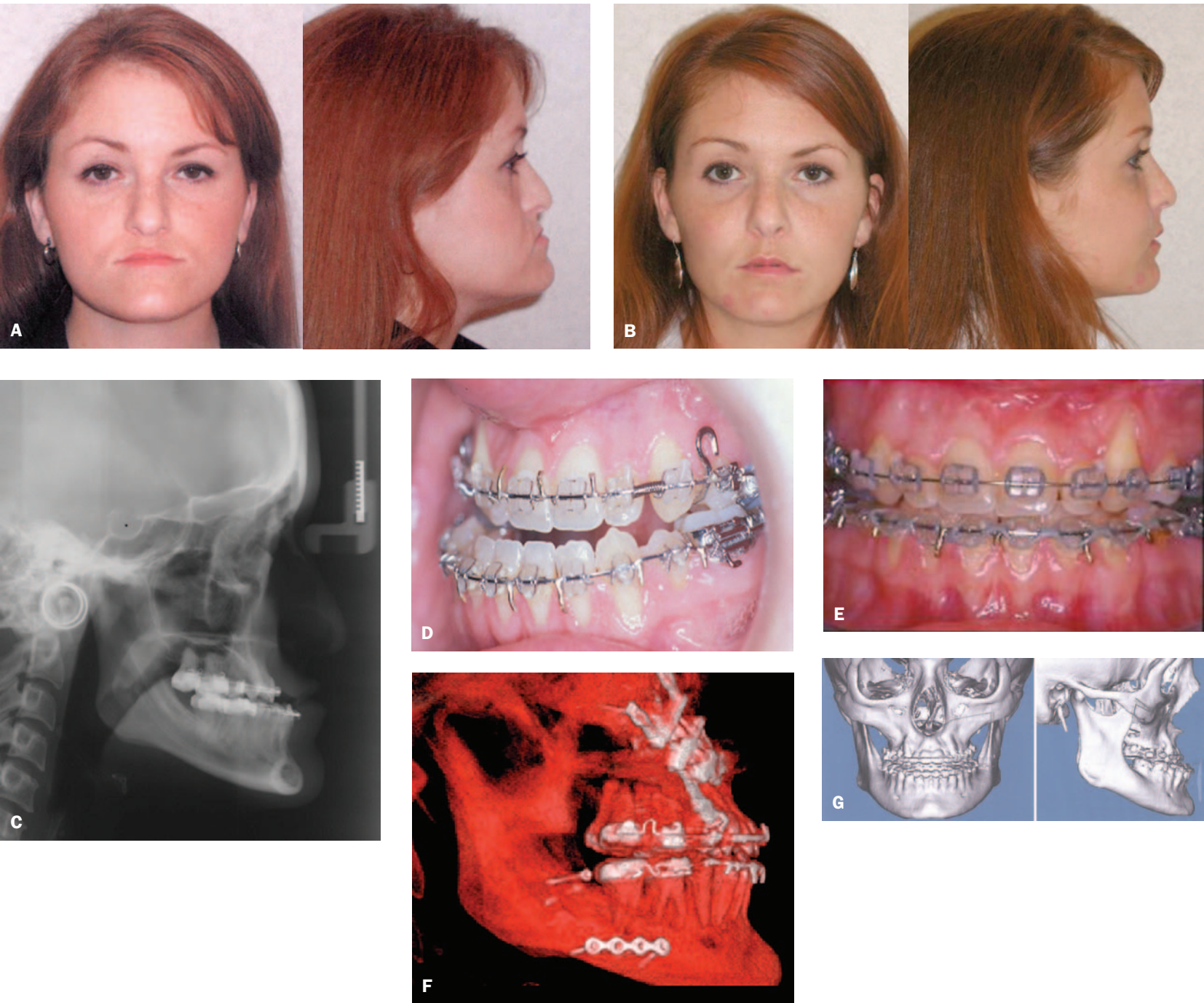


FIGURE 20-38 A, Preoperative facial appearance of 29-year-old female with severe vertical maxillary deficiency and mild anterior-posterior deficiency associated with relative mandibular excess. B, Postoperative facial appearance after distraction osteogenesis to inferiorly and anteriorly reposition maxilla (inferiorly 8 mm and anteriorly 3 mm). C, Cephalogram before orthodontic treatment showing Class III malocclusion (relative mandibular excess). Cephalograph exposed with teeth disoccluded and lips in repose used to plan amount of inferior and anterior repositioning of maxilla. D, Preoperative occlusion. E, Postoperative Class I occlusion. F, Postoperative reconstructive image showing Class I occlusion which has remained stable for 2 years. G, Plan of surgery: 3-D geometric reconstruction demonstrating planned distraction osteogenesis repositioning vectors.

the prominence of her chin, and correct her malocclusion. In addition, she was concerned about episodic pain and popping in her right temporomandibular joint. She habitually postured her mandible forward to compensate

for her retrognathic mandible and Class II malocclusion, which was associated with vertical maxillary hyperplasia. The results of the clinical assessment implicated the disparity between centric relation and centric occlusion as possible

contributing causes of her mandibular dysfunction (Figure 20-39B2 to 20-39B4). Figure 20-39B5 outlines the plan of treatment and Figure 20-39B6 shows the postoperative radiographic studies.



FIGURE 20-39

B1, Preoperative facial appearance of a 15-year-old patient and facial appearance 2 years after orthognathic surgery. B2, Presurgical Class II malocclusion before and 2 years after surgery. B3, Facial appearance 8 years postsurgery. Occlusion 8 years after surgical and orthodontic treatment. B4, Facial appearance 25 years postsurgery. Occlusion 25 years after surgery. B5, Plan of surgery. B6, Cephalographic and panoramic x-rays 25 years post surgery.

Conclusions

- 1. Three-dimensional Le Fort I/distraction osteogenesis can be used to selectively widen, lengthen, and vertically reposition the maxilla, without bone grafts or palatal incisions.
- 2. There were no healing problems, such as fibrous or delayed unions or papilla loss, observed clinically after 3-D LFI-DO.
- 3. Clinically stable Class I dental (canine and molar) and skeletal relationships can be achieved with 3-D LFI-DO.
- 4. With the use of the tooth-borne appliance, the maxillary expansion is nonparallel, greater anteriorly and inferiorly.
- 5. Long-term stability and function are predictable, stable, esthetic and functional for the majority of patients treated by well-planned and executed orthognathic and distraction procedures combined with efficient orthodontic treatment.

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Bimaxillary Transverse Osteodistraction

Maurice Y. Mommaerts

Transpalatal Osteodistraction

Tooth-borne surgically assisted rapid palatal expansion (SARPE) is an established technique to correct maxillary constriction, buccal cross-bite (unilateral or bilateral), anterior crowding, and large buccal corridors in adult patients.

Dental anchorage by tooth-borne expanders presents a number of complications, such as the following:

- Possible loss of anchorage
- Periodontal membrane compression and buccal root resorption; cortical fenestration
- Skeletal relapse during and after the expansion period, which makes overcorrection necessary
- Anchorage-tooth tipping and segmental tipping instead of parallel expansion

The TransPalatal Distractor (TPD; Surgi-Tec NV, Brugge, Belgium), a bone-borne device fixed on the palatal shelves, avoids the following problems¹:

- There is no loss of anchorage, since the abutment plates are fixed in the palatal bone.
- There is no or very little skeletal relapse, since the action of expansion and retention are immediately on the bone.
- There is no periodontal membrane compression, root resorption, or cortical fenestration, since the teeth are left untouched.
- There is no or very little tipping of the segments, since action is in a higher level on the vault.

Extra advantages include the following:

- Interchangeable modules make large expansions possible in narrow palates.
- The distractor is turned into a retainer with a locking screw.
- The TPD as retainer is tissue friendly, since it is entirely made of titanium grade 2.
- Using a distraction policy and having all teeth free for conventional bands and brackets makes commencement of alignment possible after 1.5 months of consolidation.

Step-by-Step Procedure

1. Corticotomies are performed as usual for SARPE, with transection of the median, anterior, and lateral supports (Figure 21-1). The median support is split by a median buccal sulcus approach. Septal release is not performed, even in unilateral expansion. Bleeding from a small artery within the osseous triangle forming the lateral nasal wall and lateral maxillary walls frequently occurs and must be treated adequately to avoid postoperative bleeding problems. The transection can be performed with a round bur (preferably 3.3 mm, to allow drainage into

the sinus) for the lateral support, a small Lindemann bur or a smaller round bur for the anterior support, and a 1-cm-wide sharp osteotome for the median support. Mobilization of the segments is done by prying motions with the 1-cm-wide thin osteotome (see Figure 21-1D).

2. After application of local anesthesia with a vasoconstrictor, two incisions of 1 cm length are made in the palatal gingiva over the roots of the second premolars (3:2 expansion canine: first molar) or the first molars (parallel expansion when the pterygomaxillary junction is also released) (Figure 21-2).^{2,3}

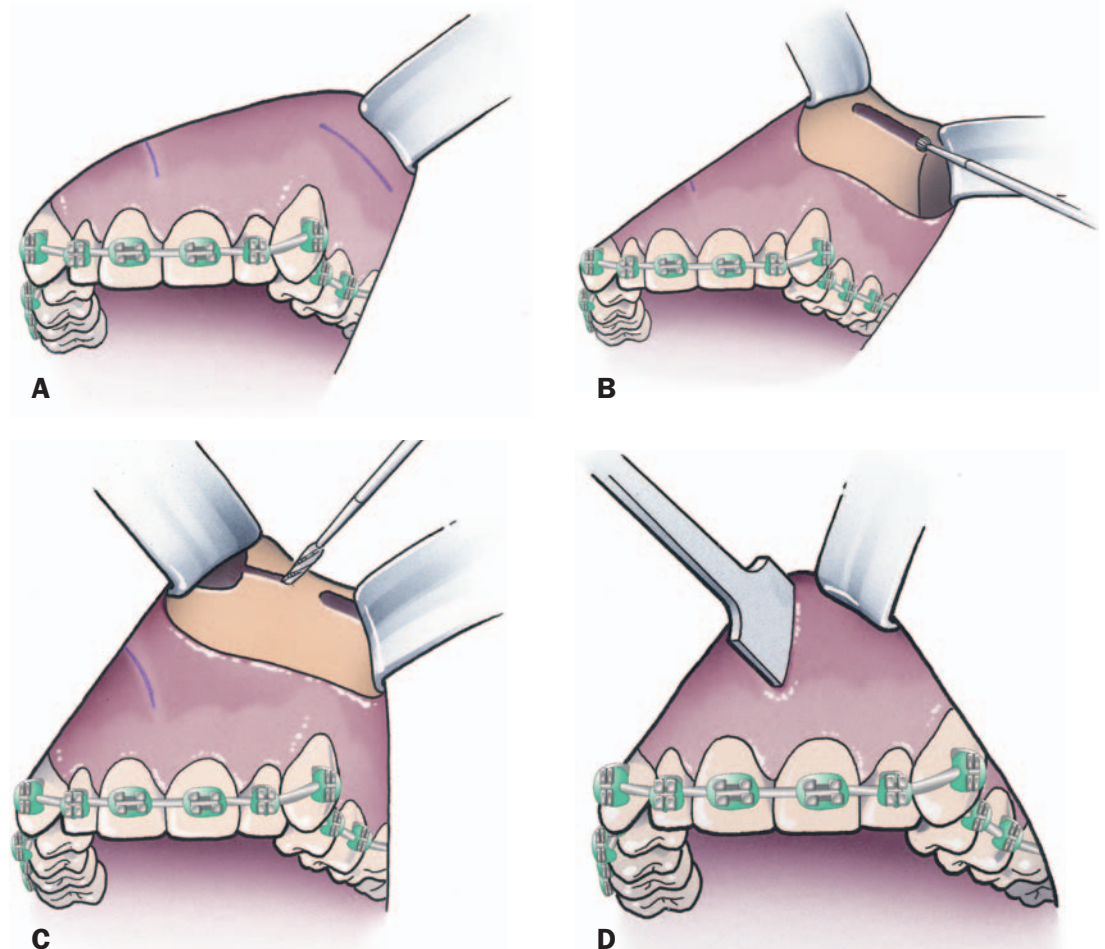


FIGURE 21-1 Corticotomies for transpalatal osteodistraction. A, Lateral buccal sulcus incision, from canine to second premolar. B, Corticotomy with round bur, rather wide at the zygomatic buttress. C, Corticotomy at the piriform aperture with Lindemann bur. D, Midline chisel osteotomy by anterior buccal sulcus approach.

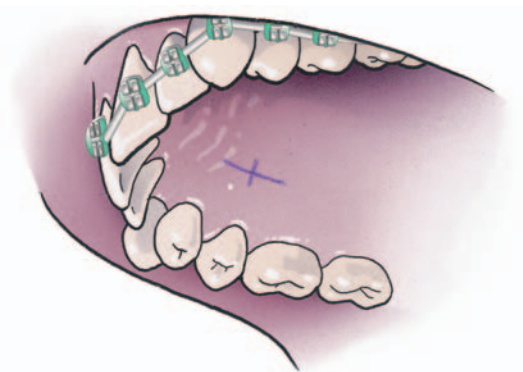


FIGURE 21-2 Cross-shaped mucoperiosteal incision at the level of the first premolar or first molar.

A small relieving incision is made perpendicular to and in the middle of the first incision.

3. The abutment plates are placed subperiosteally, on the bone surface (Figure 21-3). Care should be taken to place the box-line extensions, which are positioned 30° on the base plate, in a horizontal fashion and opposite to each other. The abutment plates are marked left (L) and right (R). Holes for the osteosynthesis screws are made with a long bur with drill bit of diameter 1.65 mm, mounted on a handpiece (Figure 21-4). The plates are fixed with 7 (or 5) mm monocortical screws of 2.3 mm diameter (Figure 21-5).

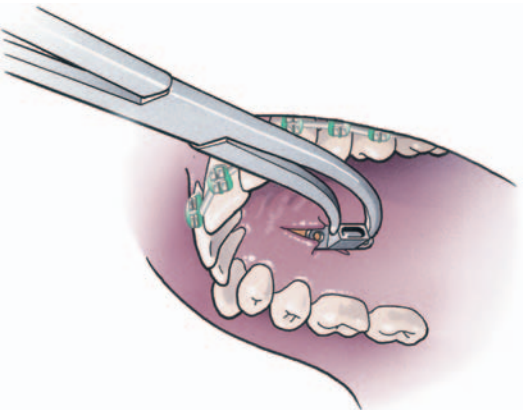


FIGURE 21-3 Placement of the abutment plates.

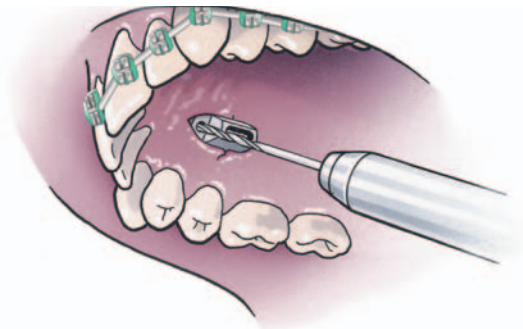


FIGURE 21-4 Drilling with a 1.65 mm drill bit.

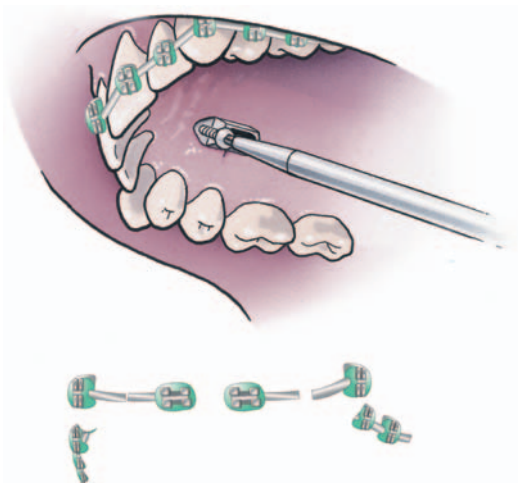


FIGURE 21-5 Fixation of the abutment plates with 7 or 5 mm osteosynthesis screws.

4. One resorbable suture on the posterior incision line is a safe measure against postoperative bleeding from the branches of the palatal artery (Figure 21-6).
5. The proper module is installed preoperatively (Figure 21-7). Placement requires some prying of the segments and adjustment of the wings of the module. The module insertion tool can be used advantageously for this

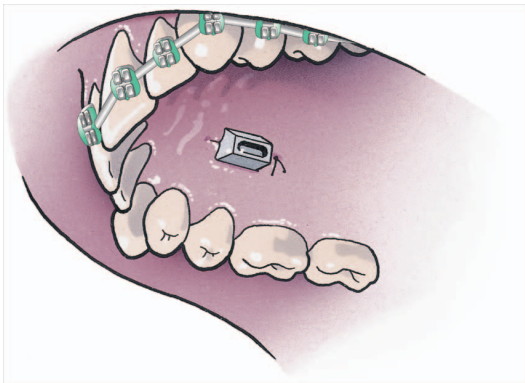


FIGURE 21-6 Safety resorbable suture over the posterior incision.

purpose (see Figures 20-7B and 20-7C). The module should be placed such that expansion will occur when the patient rotates from cranial to caudal positions. This means with the holes for the locking screw to the right. The module is secured with a locking screw. This is best done by adjusting the screw in the bone with the screwdriver insert and then mounting the straight handpiece, only to tighten the screw (Figure 21-8).

6. The module is preferably fixed to a bicuspid with a fine titanium ligature, for safety reasons. Small holes are provided in the distraction screws for that purpose (Figure 21-9).⁴

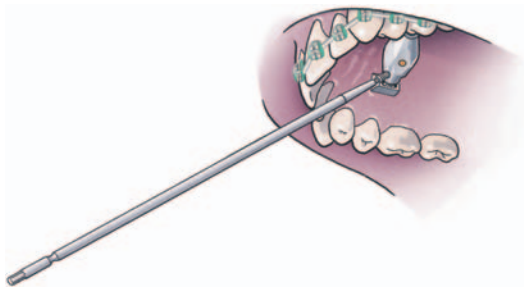


FIGURE 21-8 Placement of the locking screw, first with the screwdriver insert, and then with the handle to apply extra torque.

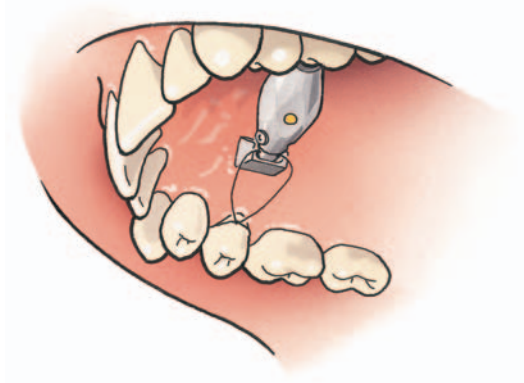


FIGURE 21-9 Safety titanium ligature around a cervix.

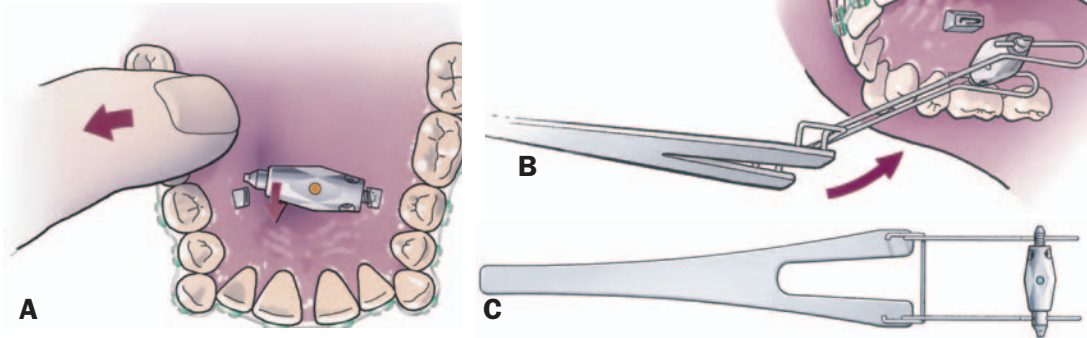


FIGURE 21-7 Placement of the appropriate distractor module. A, The fastest way is by finger manipulation. B, C, A special device can be used by the inexperienced surgeon.

7. The patient is asked to activate the device about 0.3 mm (1 color code) daily with a spanner, starting 1 week postoperatively (1 full turn = 1 mm) (Figure 21-10). The head of the spanner is turned upside down after every rotary movement. In difficult cases (restricted mouth opening), the hinge key can be useful (Figure 21-11).
8. The module can easily be changed for a larger model, when deemed necessary.
9. Once the necessary expansion is achieved, the system is locked with a small screw, with counter pressure of the index on the module.
10. Orthodontic alignment can start at 1.5 months or longer after the end of activation. Removal of the device occurs under local anesthesia, 2 months or longer after the start of the orthodontic treatment.

Transmandibular Osteodistraction

The inviolability of the mandibular intercanine distance is an old orthodontic dogma that continues to be reinforced by current research. Osteotomy techniques to narrow or angulate the symphysis are known, but infrequently used. Symphyseal widening without resorting to osteodistraction techniques is practically impossible. Immediate widening by osteotomy techniques would cause gingival trauma and denudation of the necessary bone graft and osteosynthesis material. Osteodistraction enables symphyseal broadening and allows for incisor alignment without moving the canines out of their periodontal envelope.

In the clinical setting, anterior mandibular widening by osteodistraction has been generally accomplished with tooth-borne devices. Similar problems as with tooth-borne expanders used in SARPE have been encountered in the experimental setting. These include device loosening, tipping of teeth and segments, and more dental expansion in relation to skeletal widening.

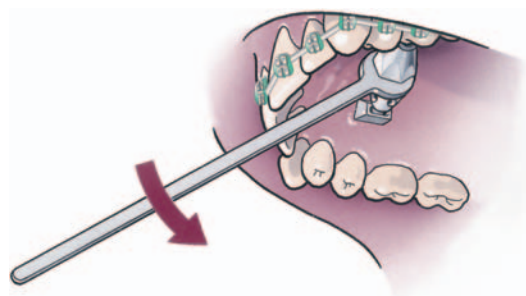


FIGURE 21-10 Activation with a simple spanner.

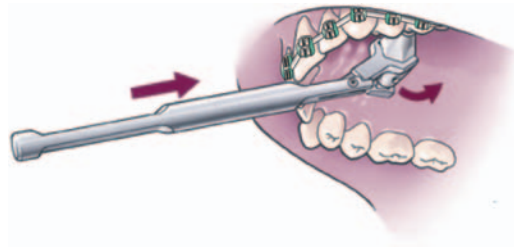


FIGURE 21-11 Activation with a hinged spanner (for patients with restricted mouth opening).

The TransMandibular Distractor (TMD Surgi-tec, Bruge, Belgium), a bone-borne device fixed on the symphyseal surface, avoids these problems.⁵

Its advantages are as follows:

- There is no loss of anchorage, since the footplates are fixed with 2 monocortical and 1 bicortical screws, at both sides of the midline.
- There is no or very little skeletal relapse, since the actions of expansion and retention are immediately on the bone.
- There is no periodontal membrane compression or root resorption, since the teeth are left untouched.
- There is no tipping of the segments, since the action is at the level of the centre of resistance.
- The activation mechanism is extramucosal; it is easily accessible for activation, it helps to control the activation rate, and it is helpful in case of a mechanical problem; it does not interfere with callus formation and maturation; removal is possible without denudation of the newly formed bone.
- Differential expansion is possible by activating one rod more than the other.
- TMD allows for symphyseal distraction along an arched segment, without the fear of instability of the fixation or of translational condylar movements, because of the helical weakening in the middle part of the rods.
- TMD is maximally tissue compatible, since it is entirely made of titanium grade 2.
- The labial sulcus incision can be kept to 15 mm, and the subperiosteal dissection can be performed medial to the mentalis muscles.

Step-by-Step Procedure

1. A horizontal labial sulcus incision of 15 mm width exposes the symphyseal surface (Figure 21-12). Subperiosteal dissection is performed

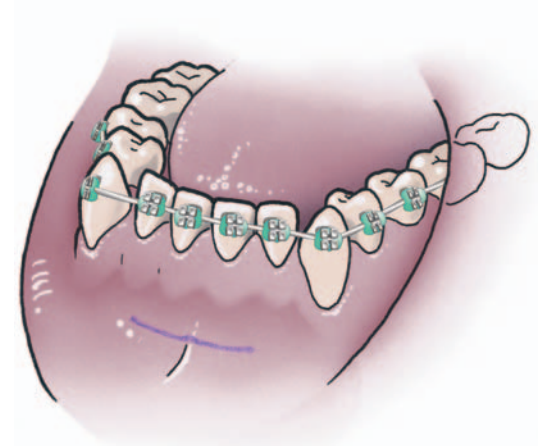


FIGURE 21-12 Horizontal incision in lower buccal sulcus, about 1.5 cm long.

in the midline, between the mentalis muscles. The mentalis muscles are not transected. A chin hook or nasal freer dissector protects the soft tissues during the osteotomy procedure. This is performed with a reciprocating saw in the chin region. In the apical region, cortical perforations are made with a small round bur. An osteotome connects them with gentle tapping and is wedged between the roots. The lingual cortex is transected with the reciprocating saw, which can now be done entirely safely in the interdental osteotomy gap. Care is taken not to tear or even to dissect the fixed gingiva (Figure 21-13).

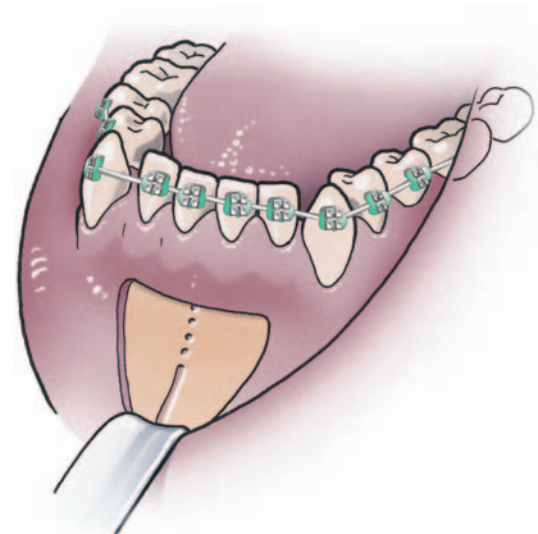


FIGURE 21-13 Subperiosteal degloving in between the mentalis muscles. Sectioning of the symphysis with a reciprocal saw, marking the interradiar osteotomy with a small round bur.

Alternatively, with wider exposure, a vertical osteotomy can be performed between the lateral incisor and canine roots, and a vertical midline osteotomy in the symphysis. Both are then connected by an oblique horizontal osteotomy under the roots of the lateral and central incisors. The mentalis muscle at the side of the step osteotomy then needs to be reconstructed. This design is favored when the roots of the incisors are very convergent.

2. The footplates are placed very close to the midline osteotomy (Figure 21-14). Holes for the osteosynthesis screws can be made with a bur mounted on a handpiece. The plates are fixed with five monocortical screws of 2.3 mm diameter in the upper and lower holes. A bicortical screw is placed in the middle hole. The incision is closed with resorbable sutures and the activation rods are covered with wax (Figures 21-15 and 21-16).

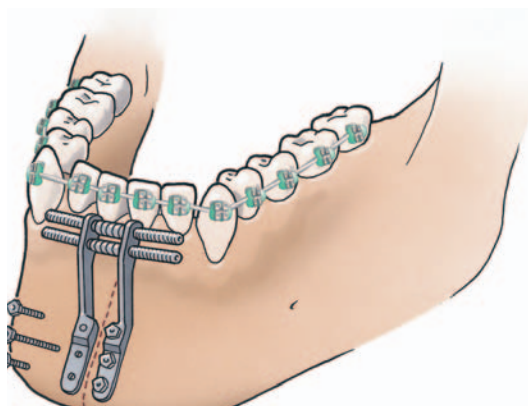


FIGURE 21-14 Placement of the distractor with four monocortical screws and two bicortical screws.

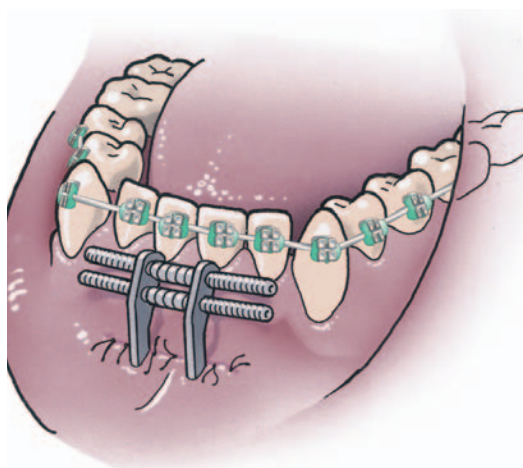


FIGURE 21-15 Water-tight closure.

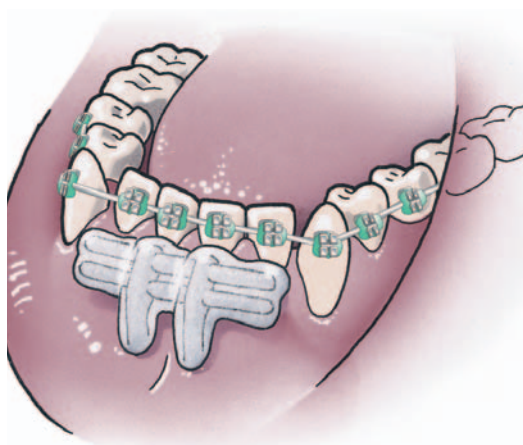


FIGURE 21-16 Protection by orthodontic wax.

3. The patient is asked to activate the device 0.5 mm daily with a spanner (1 full turn = 1 mm) (Figure 21-17). The spanner can be used at both sides. A control OPG can help to decide whether to activate one rod more than the other.

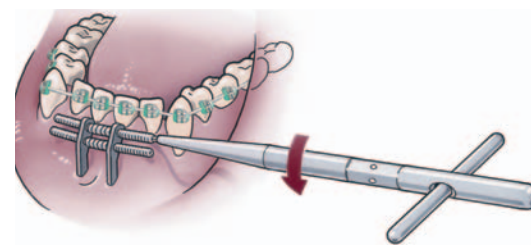


FIGURE 21-17 Activation.

4. The device is usually removed after 2 months of consolidation, and only when radiography or echography shows callus consolidation.⁶

Bimaxillary Transverse Osteodistraction

Severe crowding due to narrow upper and lower apical bases can be corrected by the extraction of four premolars, or by bimaxillary transverse osteodistraction.^{7,8} The first strategy is prone to unesthetic changes in lip posture, nasolabial angle, and buccal corridors. Life-long retention is necessary because of the known correlation between increased intercanine distance and relapse of crowding. The second strategy involves surgery, and the final outcome regarding stability is not yet known. Theoretically, because the canines have not been moved outside of the skeletal envelope, and because the functional matrix positively influences the dental arches, relapse of crowding should be less. Facial appearance is improved because of the reduction of the buccal corridors and the fullness of the mouth, both at rest and upon smiling.

Case Report

A 32-year-old female was referred by her orthodontist for a combined orthodontic-surgical treatment of her unesthetic malocclusion, which involved tapered maxilla and mandible, with anterior crowding, large buccal corridors, and mandibular hypoplasia with resulting Angle Class II malocclusion (Figures 21-18 through 21-20)



FIGURE 21-18 Case report. Facial views. A, Before treatment (June 2001). B, During osteodistraction (July 2001). C, Three months after debanding (September 2003)



FIGURE 21-19 Case report. Occlusal views of the maxilla. A, Before treatment (June 2001). B, During osteodistraction (July 2001). C, Three months after debanding (September 2003).



FIGURE 21-20 Case report. Occlusal views of the mandible. A, Before treatment (June 2001). B, During osteodistraction (July 2001). C, Three months after debanding (September 2003).

The patient underwent osteodistractor day-case surgery in June 2001, comprising placement of a transpalatal distractor at the level of the second premolars, corticotomies without pterygomaxillary disjunction, placement of a transmandibular osteodistractor, vertical osteotomy in the symphysis, and removal of the right lower third molar. Distractor activation started 1 week later and was ended in the beginning of July 2001. The transmandibular distractor was removed in October 2001, and the transpalatal distractor was removed in November 2001, both in an office-based procedure using local anesthesia only. Fixed orthodontic appliances were applied

in October 2001 for alignment, decompensation, and coordination of the arches. In February 2003, the patient underwent mandibular advancement and genioplasty surgery. The orthodontic appliances were removed in June 2003 (see Figures 21-18 through 21-20).

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Distraction Osteogenesis of the Maxilla at the Le Fort I Level Using an Internal Distractor

David M. Kahn and Stephen A. Schendel

A Le Fort I osteotomy with distraction osteogenesis is a complementary, not a competing, technique to a conventional Le Fort I osteotomy in which immediate movement of the maxilla into the desired position and miniplate fixation is done in a single operation. In essence, this is an additional tool to be used in a situation in which conventional orthognathic surgical techniques yield either a suboptimal esthetic result or are associated with an increased risk of relapse. This is the case in severe maxillary and midface deficiency. Le Fort I maxillary distraction is indicated in those situations in which an advancement over 6 to 8 mm is needed with bone grafting^{1,2} or in cases in which a soft tissue scar can limit the amount of advancement possible.

Distraction osteogenesis has now become an established tool in the armamentarium of the craniofacial surgeon to achieve bone lengthening and to correct for malposition of the bone within the three-dimensional framework of the facial skeleton. Rachmiel and colleagues used a sheep model to validate a role for distraction osteogenesis to generate bone growth and alter the position of the bones of the midface.³ The technique was introduced into the clinical arena for use in cases of maxillary and midface hypoplasia by Molina and Ortiz-Monasterio.⁴ At present, several choices of distraction devices are available for maxillary distraction. These devices can be external or internal in design.^{1,2,5-8} External devices, such as the rigid external distractor (RED) developed by Polley and Figueroa,¹ are anchored to the skull superiorly. Internal devices are anchored above the Le Fort I osteotomy to either the malar prominence of the zygoma or the zygomatic buttress. Inferiorly, below the osteotomy, both the external and internal devices can be anchored either to the dentition or directly to the bone of the maxillary Le Fort I segment.

External halo-based devices are currently used more commonly than internal devices in distraction.⁹ Devices such as the RED are easy to

use, allow for multivector positioning, and are reliably effective in achieving maxillary advancement. The drawbacks to an external device are that their use requires intensive preoperative and postoperative support from the medical team during the treatment period. Patients find the device uncomfortable, and eating poses a significant challenge.¹⁰

Intraoral devices have several potential advantages over their external counterparts. The devices are hidden from view and thus better tolerated. This chapter presents our experience using a bilateral intraoral device that is anchored on the malar prominences subperiosteally and either subperiosteally on the bony Le Fort I segment or wired to the maxillary dentition.

Distractor Design

The senior author (S.A.S.) developed the distractor. It is a bilateral intraoral device (Figure 22-1) with a footplate that contains a cup that is placed into a drill hole in the malar prominence and is

also anchored by screws to the bone subperiosteally above the osteotomy. The upper plate is joined to the activation mechanism, which then joins an arch bar and the lower footplate. The activation mechanism of the device is located intraorally. The lower footplate can be anchored to the bone of the Le Fort I segment below the osteotomy if desired. The arch bar joins the two hemidistractors and can be wired directly to the maxillary dentition. The ability to anchor directly to bone, the dentition, or both allows for considerable flexibility in using the distractor. This arch construct with both tooth- and bone-borne anchorage leads to considerable stability of the device. It also allows the forces of distraction to be shared across a larger surface area, delivering a more uniform and reliable vector of distraction.

Surgical Technique

If indicated, patients will undergo preoperative orthodontics to align the dental arches and eliminate compensations. Surgical planning to

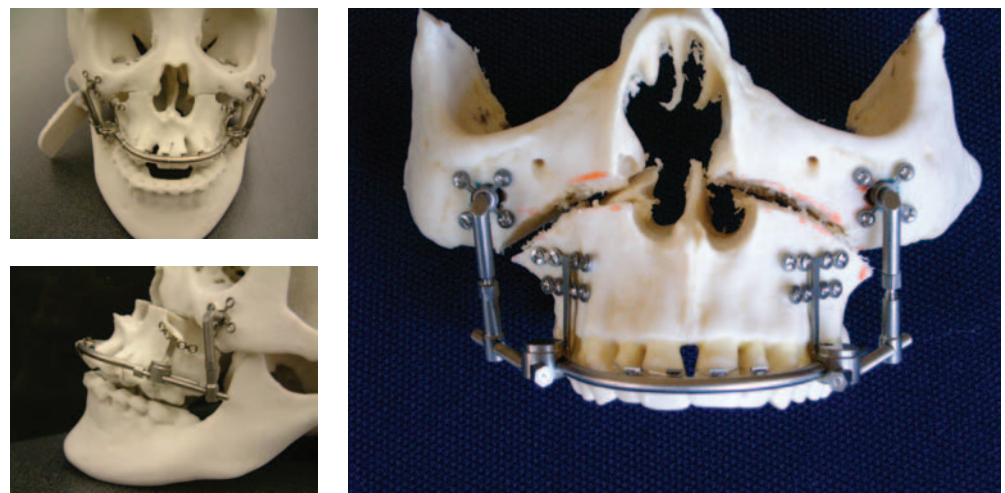


FIGURE 22-1 Internal maxillary distractor design.

determine the vector of distraction uses a lateral cephalometric radiograph, visual treatment objective using Delaire analysis, a panorex, and dental models. In our early cases, we also used a three-dimensional computed tomographic scan and stereolithographic model to assist in planning placement of the devices.

A Le Fort I osteotomy is performed. The level of placement of the osteotomy depends on the location of the tooth roots and developing tooth buds when present, as well as the level of midface correction desired. A complete osteotomy is performed with pterygomaxillary and septal disjunction. The Le Fort I segment is then moderately mobilized.

A guide hole is drilled in the malar prominence, and then a larger hole is drilled to accept the post of the upper footplate. The malar footplate is then also secured to the bone with two to four screws. The device is then placed in the malar “star” and anchored. Anchorage below the level of the osteotomy can be done by securing the lower footplate to the bone with 2 mm screws, and/or by wiring the arch bar to the dentition with 26-gauge wire. The device is activated to ensure proper functioning, and a 4 mm gap is left prior to closure. The mucosal incision is then closed around the device.



FIGURE 22-2 Activation of the distractor.

Distraction Protocol

Distraction is initiated after a 2- to 4-day latency period. The activation mechanism is turned one full rotation (0.33 mm) three times a day for a rate of 1 mm/day (Figure 22-2). Distraction continues until the desired occlusion is achieved. The device is then left in position for a 2-month retention period. On completion of the consolidation period, the device is removed in the operating room. The patient then resumes orthodontic treatment with a Delaire face mask to retain the position of the maxilla.

Clinical Experience

Six patients with nonsyndromic cleft lip and palate have undergone distraction of the maxilla using this device. The device was anchored to the bone and teeth in all cases. The average distraction distance was 13.4 mm. Distraction was well tolerated by the patients. There were no major or minor complications. The results maintained stability throughout the 4-month follow-up period. A representative case is shown (Figures 22-3 to 22-6).

Discussion

In managing patients with moderate to severe maxillary deficiency, the traditional orthognathic



FIGURE 22-3 Preoperative photographs of an 18-year-old patient with a unilateral cleft lip and palate and severe maxillary hypoplasia.

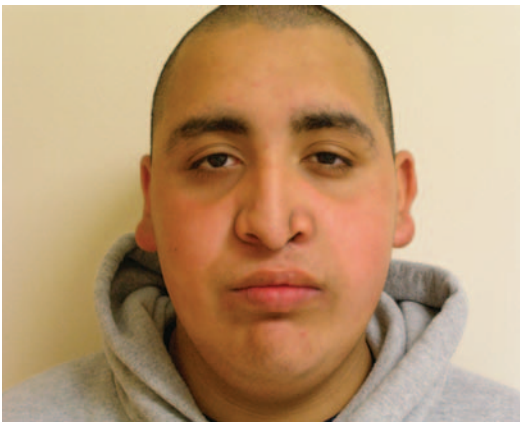


FIGURE 22-4 Postoperative photograph of the patient in Figure 22-2.



FIGURE 22-5 Pre- and postoperative cephalometric radiographs of the patient in Figure 22-2.



FIGURE 22-6 Pre- and postoperative occlusions of the patient in Figure 22-2.

surgical technique of Le Fort I osteotomy with intraoperative positioning of the maxillary segment and miniplate fixation has had mixed results. Often the skeletal dental deformity remains undercorrected. Conventional orthognathic surgery in cleft palate patients with severe maxillary deficiency is associated with relapse rates, which are reported to be around 20%.¹¹⁻¹⁴ These patients also experience a deterioration in

velopharyngeal function.¹⁵ Many of these cases undergo additional procedures to correct these poor outcomes.

Another approach is a more limited maxillary advancement combined with a mandibular setback as an attempt to correct these deformities with less risk of relapse. This approach is often chosen if it is felt that the soft tissue envelope will limit the amount of intraoperative advancement

or the amount of advancement is large. This treatment plan often involves setback of a mandible that is normal in both size and position. The two-jaw surgical approach can correct the malocclusion but often results in compromised facial esthetics.

Distraction osteogenesis of the maxilla is a complementary technique to the traditional intraoperative advancement and miniplate fixation of the Le Fort I maxillary segment. The technique of maxillary advancement by distraction offers several advantages for the patient requiring a large advancement greater than 6 to 8 mm or in whom significant scar tissue may limit the amount of advancement. It allows for gradual stretching and expansion of the soft tissue matrix to accommodate the advanced bony framework.

Several studies have attempted to evaluate the changes in speech after distraction osteogenesis. Guyette and colleagues evaluated the changes in velopharyngeal function after maxillary advancement using a RED device.¹⁶ They found the risk of hypernasality to be similar to that seen with conventional advancement techniques. Rabin and colleagues, however, reported better speech results in their patients with severe cleft maxillary deficiency undergoing internal distraction compared with those undergoing conventional advancement.¹⁴ Further studies are needed to evaluate the effect of distraction osteogenesis on speech, but these early reports suggest that speech outcomes are as good as and possibly even better with distraction osteogenesis. It may be that the gradual daily advancements allow the soft palate to accommodate to the changes that occur in the velopharyngeal mechanism.

In addition, bone distraction generates bone formation at key support regions, such as the pterygomaxillary junction.^{6,17} This results in increased stability of the final result. It also obviates the need for bone grafts and the morbidity associated with bone graft harvest. It reduces and potentially can eliminate the need to set back a normal mandible. With distraction osteogenesis, maxillomandibular fixation is not used, and miniplate fixation is not typically needed, although a miniplate can be placed at the time of distractor removal if desired.

Both external and internal devices exist for Le Fort I distraction. Swennen and colleagues reviewed the published clinical studies of distraction osteogenesis in 2001.⁹ In their article, they noted that over 90% (117 of 121) of the reported cases used an external device to advance the maxilla. This is most likely related to the more rapid development and ease of use of external devices as opposed to internal devices for clinical use.

External distractors have seen a progression of development in device design from face masks to the current RED systems.^{6,18} Molina and Ortiz Monasterio reported the first clinical cases

of maxillary distraction.⁴ The distraction was achieved by using a face mask to deliver 900 g of force to an intraoral device applied to the maxillary dentition. Subsequent authors reported unsatisfactory results with the technique that were unstable over time using the face mask to generate the distraction forces.¹⁹

These unsatisfactory results with face-mask distraction led Polley and Figueroa to develop the RED.¹ The RED device consists of a halo anchored to the skull with pin fixation. An intraoral appliance is anchored to the dentition and attached by traction wires to the distraction screws. Plates attached to the Le Fort I maxillary segment can be used in place of the intraoral appliance. The distraction screws are located on a horizontal bar that is connected to the vertical bar component. The vertical bar rests in front of the face secured to the halo.

The RED has been very successful in achieving stable correction of severe maxillary deficiency.^{17,19} The device is easily placed during surgery and can be removed in the office in older patients, although younger children may require a return to the operating room for removal. The device is easily adjustable, making it possible to change the vector of movement during the distraction process. The possibility of multivector advancement makes three-dimensional corrections possible. Because the device is external and not limited by space constrictions, distraction distances of greater than 15 mm can be achieved.²⁰ In addition, the RED with dental anchorage can also be used in younger patients, in whom hardware placement would risk injury to the developing dentition.

Although the RED has been a very successful appliance for achieving distraction, several disadvantages to the device exist. Figueroa and colleagues noted that the device is well accepted, especially with adequate patient education.¹⁷ However, there is no denying that an external device displays the stigmata of treatment, and many of our patients undergoing RED distraction are homeschooled during the treatment period, which can last for 3 to 4 months.

We have had problems with the pin fixation loosening from the cranium. The instability of the halo that results from the loosening of the pins can decrease the effectiveness of distraction and alter the vector. Furthermore, in younger children, repositioning of the halo or tightening of the screws may warrant a return trip to the operating room. Pin-site infections and intracranial migration of the pins are also a risk of the halo.²¹

Rieger and colleagues reported on a child who fell with the RED device in place.²² As a result, the child sustained a temporoparietal skull fracture with associated dural tears. These injuries were repaired in the operating room, and the child recovered uneventfully from this accident.

The child continued to undergo distraction, and the final result was not compromised. Serious complications such as these are a risk of external distractors that have halo fixation and could be eliminated with the use of an internal distractor.

Distraction devices with tooth-borne fixation have limitations as well. Forces applied to the dentition can cause movements of the teeth within the bone, thus decreasing the effective distraction on the maxilla and altering the position of the teeth within the maxillary arch.²³ Molina and colleagues described greater advancement of the lateral segment in patients missing the lateral incisor.⁶ This resulted in pulling of the canine into the space normally filled by the lateral incisor. We have also experienced a case in which the appliance lost its fixation to the dentition and needed to be reanchored.

Swennen and colleagues, based on their review of the clinical results of the published literature on distraction osteogenesis, recommended that longer retention periods are necessary in the maxilla as opposed to the mandible owing to the thinness of the bone at the distraction osteotomy site.⁹ They also advocated for the use of devices with a 1:1 movement ratio. Internal distraction devices offer these advantages over external ones.

Patient comfort and tolerance with the internal device are much improved as the stigmata of the external halo are eliminated. Because the device is less visible and is better tolerated, retention and consolidation periods can be increased. An increased duration of stability in the consolidation phase of distraction results in the formation of an optimal bony regenerate.

Previous work in our laboratory has shown that internal devices offer increased stability and a decrease in the amount of torque on the distraction device during the activation process.²⁴ This increased stability translates into a better environment for bone regeneration and a closer correlation between predicted and expected amounts of distraction. Thus, the criteria of a 1:1 distraction are met. The wires of the RED distractor are prone to stretch and absorb much of distraction force, and the potential for halo movement will make a 1:1 distraction much harder to achieve. As we noted early, the external device allows for changes to the vector of movement to be made during the activation period, but it can be difficult to control the vector, resulting in the desired occlusion not meeting the goals of the treatment plan.¹⁷ Moreover, there is less stability of the external construct, leading to a suboptimal environment for bone formation.

The distractor design presented in this chapter has several advantages over external designs, as well as other internal distractor designs. The device is anchored bilaterally to the zygomaticomaxillary buttress above the osteotomy. This is a

very stable anchorage site, as noted by Cheung and colleagues.²⁵ In addition, the device can be anchored to the teeth and maxillary bone below the osteotomy. This allows for the forces of distraction to be distributed more equally. The arch bar joining the two hemidistractors lends even more stability to the construction of the distractor, in addition to making the placement of the device easier and more precise. Furthermore, in younger children with developing tooth buds, the device can still be used and anchored to the dentition alone.

Disadvantages of internal devices do exist, however. As the distraction proceeds along a single vector, precise presurgical planning is the key to success. Postdistraction molding of the regenerate can be helpful to optimize the final result. In addition, the length of the activation mechanism and the amount of space in the buccal vestibule limit distraction distances. Our distractor has overcome this limitation in design and allows for a possible 25 mm of distraction. A surgical procedure is required to remove the distractor; however, if desired, miniplate fixation can be placed at the time of device removal.

The intraoral portion of the device can be irritating to the mucosa. The opening of the buccal mucosa to accommodate the transition of the device from its intraoral to its internal position is also a portal of entry to infection. This requires strict attention to oral hygiene to reduce the risk of infection. Infection has been well tolerated and managed by oral antibiotics, with no delay in treatment.

Le Fort I maxillary advancement with distraction osteogenesis is a complementary tool to conventional orthognathic surgical techniques that address maxillary deficiency. It is the technique of choice for patients who require a significant maxillary advancement of more than 6 to 8 mm or have significant soft tissue limitations, such as scarring secondary to previous surgical procedures. The procedure can be performed in children prior to reaching skeletal maturity. Finally, maxillary advancement by distraction of the Le Fort I segment offers an improved esthetic outcome and less risk of deterioration of speech when compared with traditional orthognathic techniques.

We present our experience with a new design for internal distractors of the maxilla. This design offers an improvement over both external distractors and other internal devices. It is anchored to thick bone stock and has a construction that distributes forces for distraction equally. The device can also be anchored to the dentition, extending its applicability to children in the phase of mixed dentition. Finally, the device is easier to place than other designs, and because it is entirely intraoral, it is better tolerated by patients and can be left in place for longer retention periods.

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Lengthening the Maxilla by Distraction Osteogenesis

Thomas Hierl

Distraction osteogenesis (DO) is no longer an experimental procedure in the treatment of severe bony hypoplasia or maxillomandibular retrusion. Apart from earlier case reports, there is now 10 years of experience with this procedure.¹ This chapter deals with the therapy of maxillary retrusion and hypoplasia by way of DO. Although different treatment concepts using intraoral and extraoral devices exist, only extraoral halo-borne distractors are described. Reasons are given in this chapter on advantages and disadvantages. When speaking about maxillary procedures, the decision of where to cut the bone is dictated by the present pathology and not by the device used in most circumstances. The described technique works with all osteotomies which lie between the Le Fort I and Le Fort III levels.

Indications

There is a generally accepted list of indications in which DO of the maxilla should be taken into account:

In adult patients with a retrognathic maxilla:

- If the maxillomandibular discrepancy is > 10 mm (Figure 23-1)
- In case of significant relapse after conventional orthognathic surgery
- In case of a lack of soft tissue or severe intraoral scarring, as in some cleft lip and palate patients, or if extremely tight velopharyngeal flaps are present (Figure 23-2)
- Severe maxillary retrusion in edentulous patients with thin, brittle bone in whom miniplating may be difficult (Figure 23-3)

In junior patients:

- If there is a major maxillomandibular deficiency (> 9–10 mm) at age 9 to 11 years when no more “catch-up growth” of the midface may be expected. Then the final sagittal discrepancy between the maxilla and the mandible in an adult will be extremely severe if no treatment is performed.



FIGURE 23-1 Computed tomographic reconstruction of an 18-year-old girl suffering from unilateral cleft lip and palate. Marked midfacial retrusion. Preoperative situation.



FIGURE 23-3 A 35-year-old male patient with unilateral cleft lip and palate. Marked midfacial retrusion and atrophy. The preoperative situation is shown (all computed tomographic rendering was done with Vworks, Cybermed, Korea).



FIGURE 23-2 Tight velopharyngeal flap with significant scarring before maxillary distraction.

In all groups, most patients treated will suffer from cleft lip and palate. In younger children with a severe retrognathic midface, a Delaire mask might be tried alternatively, but one should keep in mind that only minor corrections between 2 and 4 mm will be achieved in most cases and that these children might be unwilling to participate in further procedures, such as DO.

Contraindications include any risks for which surgery is not suitable. In the early deciduous dentition, there will be a risk of violating the permanent tooth buds, especially the canine. This will be minimal if patients older than 10 years are operated. Treating junior patients, one has to realize that the definite subsequent growth is unknown. Major maxillary growth after DO will not occur in most instances, and mandibular development may vary. Therefore, secondary orthognathic procedures may be necessary later. There is, however, a significant advantage if severe maxillomandibular deficiency is treated in junior

cleft palate patients. In these cases, the muscular imbalance between the upper and lower lips will improve significantly after maxillary advancement, which is difficult to correct in adult patients (Figure 23-4). Furthermore, logopedic therapy will be more effective.

Advantages and Disadvantages

DO versus Conventional Orthognathic Surgery

Listing the advantages and disadvantages between conventional orthognathic surgery and DO is somewhat problematic as the patient groups may differ significantly. The greatest advantage of DO is treating the pathology in the appropriate jaw if there is a major maxillary retrusion, and no ancillary mandibular setback surgery is needed. By now, there seems to be no upper limit in the protraction performed, and my own maximum maxillary advancement is 31 mm. Regarding esthetic outcome, the results might be superior if only the retrognathic maxilla is advanced, as in cleft palate patients, and there is no soft tissue sagging in the neck and chin area when the setback of a “normal” positioned mandible can be avoided. With respect to the technical aspects, advantages of DO are that there is no need for intermaxillary fixation throughout the whole treatment procedure and oral hygiene can be well performed. Furthermore, there are no dietary

problems as soft meals like noodles, hamburgers, rice, or vegetables can be eaten. On the other hand, only partial maxillary intrusion can be accomplished with DO, and multisegment procedures (with the exception of transversal widening) are difficult to perform. Regarding postoperative stability, DO seems to be a secure treatment, as shown in Figure 23-5. After advancement, overcorrection, and postoperative finishing with elastics, angle between Sella-Nasion-A

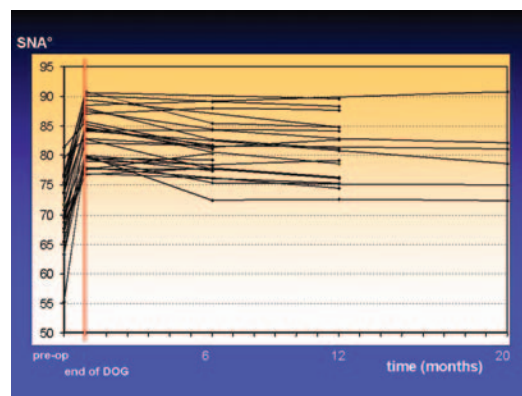


FIGURE 23-5 Changes in SNA° in the first 22 patients treated with the halo frame-based distractor. After overcorrection, the definite occlusion was achieved with intermaxillary elastics, which explains some of the “relapse” seen initially. After occlusal settling, SNA° remained comparatively unchanged.



FIGURE 23-4 An 11-year-old boy with bilateral cleft lip and palate. A shows the predistraction situation with the typical dish-face appearance and muscular lip imbalance. The situation over 1 year after distraction osteogenesis is seen in B. There is good midfacial convexity and markedly improved lip balance. Logopedic training for lip competence is now possible.

point defining the sagittal position of the maxilla relative to the frantal skull base (SNA°) remained stable in our own group.

Extraoral versus Intraoral Devices

As in mandibular DO, the first commercially available systems have been external devices (RED device, Martin Medizintechnik, Tuttlingen Germany). To solve the problems of distractor fixation, the halo frame seemed the ideal solution. As it is a bulky device, “smart” internal hardware has been developed,^{2,3} which, however, is not able to fulfill all of the tasks needed in many instances. A common prejudice of surgeons is that patients will not like halo frames and will reject treatment. In our own patient group, only 2 of 45 patients opted against the device after the therapeutic concept was explained.

There seem to be three advantages of internal devices:

- They are inconspicuous.
- A longer retention time is possible until removal of the device.
- In case of previous skull surgery with a lack of calvarial bone, halo frames might not be used.

On the other hand, the advantages of external devices are as follows:

- There is no limitation in advancement.
- There are no problems with device fixation (eg, parallel adjustment, divergence of left and right distraction vectors).
- There is absolute freedom in the design of the osteotomy line (no problems with fixation of the device superior to the osteotomy).
- The distraction vector can be altered during treatment.
- The device can withstand heavy forces, is quite robust, and is easily understandable by patients and parents (no problems with delicate intraoral device activation).
- Adjacent procedures may be performed simultaneously (like rapid maxillary expansion with a hyrax appliance; Figure 23-6).
- Using an external device delivers constant tension forces on the maxilla throughout the distraction process as the connecting wire, the vertical carbon fiber rod, and the retention system bars act like a buffer (although the value of this benefit is unclear at the moment).

Functional Aspects

Functional aspects must also be considered. Large maxillary advancements in cleft lip and palate patients may cause or worsen velopharyngeal incompetence,⁴ and a large unimaxillary procedure, rather than a bimaxillary procedure, might result in an inferior speech outcome. In my team’s own investigation of 24 cleft lip and palate patients

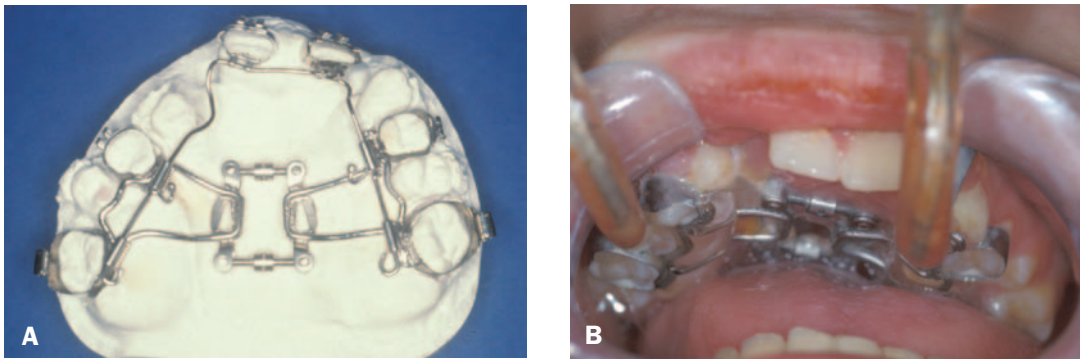


FIGURE 23-6 Examples of simultaneous transversal procedures. A shows a Nardella-type device to widen or constrict the maxilla with simultaneous premolar uprighting. B, Patient wearing a Nardella device for transversal widening during distraction osteogenesis. As there is no rigid connection between the maxillary halves and the extraoral distractor, simultaneous widening is easy.

with a mean advancement of 17.8 mm, we saw a deterioration in 5 patients (21%) and an improvement in 2 cases (8%).⁵ In 3 of 35 patients with a postoperative follow-up over 1 year, subsequent velopharyngeal flap surgery was performed (9%). All of them, however, had marked velopharyngeal incompetence before DO, which worsened during treatment.

Regarding nasal respiration, 25 patients in our group were investigated by means of rhinomanometry and acoustic rhinometry before and after DO. Here an improvement between 155 and 207% in total nasal airflow without nasal decongestion could be seen. Nasal cavity volume increased up to an average of 139%.⁵

Biomechanical Aspects: Vector Control

One of the most challenging aspects of DO is vector control. Most patients planned for maxillary distraction need not only sagittal advancement but also some degree of clockwise rotation to close an anterior open bite and elongate the midface. Using intraoral monodirectional

devices, the latter is hard to reach and can be achieved only with postoperative elastics. Placement of the distractors is crucial and may end up with unacceptable results.⁶ Extraoral devices, on the other hand, offer the possibility of changing distraction vectors at any time. To highlight the basic physical rationale of vector control in halo frame-based maxillary DO, Figure 23-7 shows the relationship between the center of resistance and the point where tensional force is applied. This implies that any force inferior to the center of resistance leads to an anterior open bite, whereas superior forces work in the opposite way. Although the exact center of resistance of the maxilla is unknown and soft tissue influence by the muscles of cheeks and soft palate or velopharyngeal flaps must be considered, a location somewhere superior to the premolar roots has been suggested.⁷ A clinical example will demonstrate the implications. Figure 23-8A shows the preoperative cephalogram of a young man suffering from bilateral cleft lip and palate. After surgery, a dental splint for protraction was cemented (Figure 23-8B). To achieve the

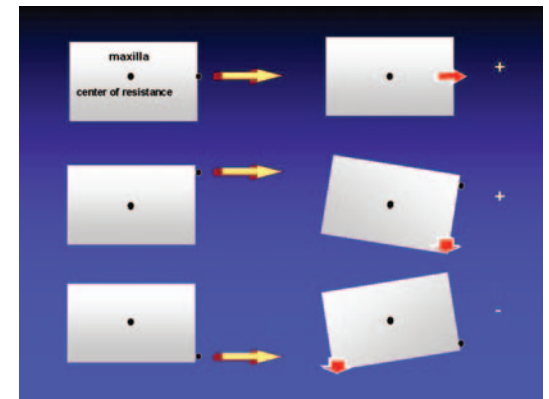


FIGURE 23-7 Sketch to demonstrate the relationship of the center of the mass (center of resistance) and the point of force application. Tension applied inferior to the center of resistance leads to an (in most cases) unwanted counterclockwise rotation and an anterior open bite.

clockwise rotation, the extraoral bars had been designed quite long. One of these rods broke during distraction; thus, the wire connecting the maxilla and the distractor had to be fixed to the intraoral appliance (Figure 23-8C). One week later, a beginning anterior rotation was seen (Figure 23-8D), which ended up in a marked anterior open bite before distractor removal (Figure 23-8E). Elastics and orthodontic therapy improved the situation somewhat; nevertheless, further orthognathic surgery for posterior intrusion had to be done later.

To control the problem of vector control and avoid the risk of dental extrusion, a miniplate-based bony anchorage system was devised (Leipzig retention plate, Martin Medizintechnik, Germany).⁸ It consists of a miniplate holding a rider, which fixes a strong 1.8 mm² square steel bar. This bar runs around the upper lip, ending lateral to the nasal alae. To connect the wire to the spindle

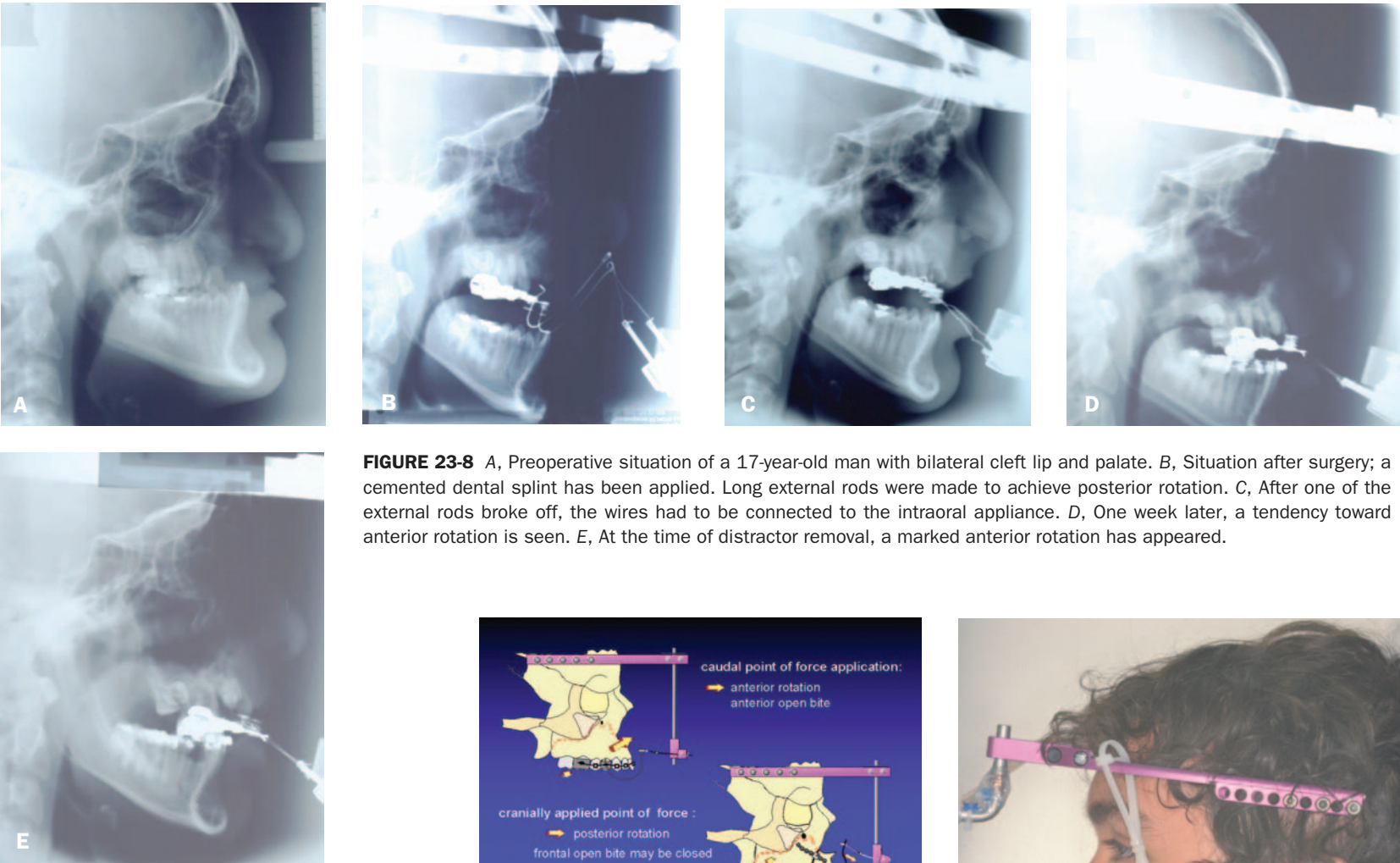


FIGURE 23-8 A, Preoperative situation of a 17-year-old man with bilateral cleft lip and palate. B, Situation after surgery; a cemented dental splint has been applied. Long external rods were made to achieve posterior rotation. C, After one of the external rods broke off, the wires had to be connected to the intraoral appliance. D, One week later, a tendency toward anterior rotation is seen. E, At the time of distractor removal, a marked anterior rotation has appeared.

units of the external distractor, eyelets are screwed on (Figure 23-9). Thus, it is possible to achieve the intended point of force application by bending the bar before fixation (bending is not possible after the system has been attached to the patient) and moving the eyelet (which can be done at any time). Figure 23-10 shows the difference between a dental splint and the miniplate retention system.

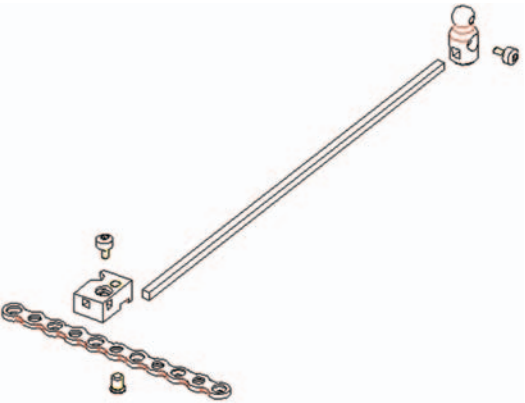


FIGURE 23-9 The modular miniplate system for bony anchorage consisting of a miniplate and a rider that is screwed on from the back of the plate. It serves to hold a strong 1.8 mm square bar, which is bent to run around the upper lip. The eyelet is connected via wire to the external distractor.

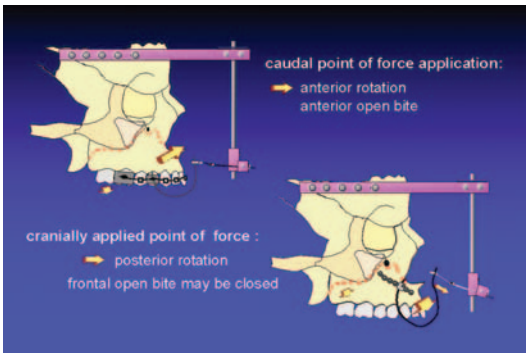


FIGURE 23-10 Situation of Figure 23-7 applied to clinical practice. Using a dental splint with short extraoral rods does not permit posterior rotation. A longer extraoral rod would improve the situation but tends to bend and exerts heavy extrusive forces on the upper dentition. Using the miniplate retention system avoids these problems. Note that the miniplate is fixed to the zygomatic buttress posteriorly.

One of the drawbacks of maxillary DO is that no intrusion can be performed. In cases of a severe anterior open bite in which posterior maxillary intrusion is needed, however, the following procedure has proven successful: after sagittal advancement has been achieved to at least two-thirds, a headgear is put into the tubes on the first/second molars and the external arms are connected to the halo frame (Figure 23-11). Three to five N should be enough to intrude the maxilla into the desired position. As this exerts heavy forces on the skull, care should be taken that the strong bone is used for anchorage to avoid skull perforation or fracture. Figure 23-12 shows the course of treatment. As the desired posterior rotation was not achieved, a headgear was used successfully (shows the situation 1.5 years later).



FIGURE 23-11 A 23-year-old man during treatment. To achieve posterior maxillary intrusion, a headgear appliance has been used. Intrusive force was 5 N (note that the halo frame distractor system is non-standard and has been modified to measure distraction forces).

The reason why the posterior rotation could not be achieved without the headgear, although the biomechanical factors seemed correct, is speculative. The thick, scarred velopharyngeal flap is supposed to have hindered maxillary rotation (Figure 23-13). To analyze bony changes and investigate force-movement relationships, a special software was developed.⁹ Figure 23-14 shows the

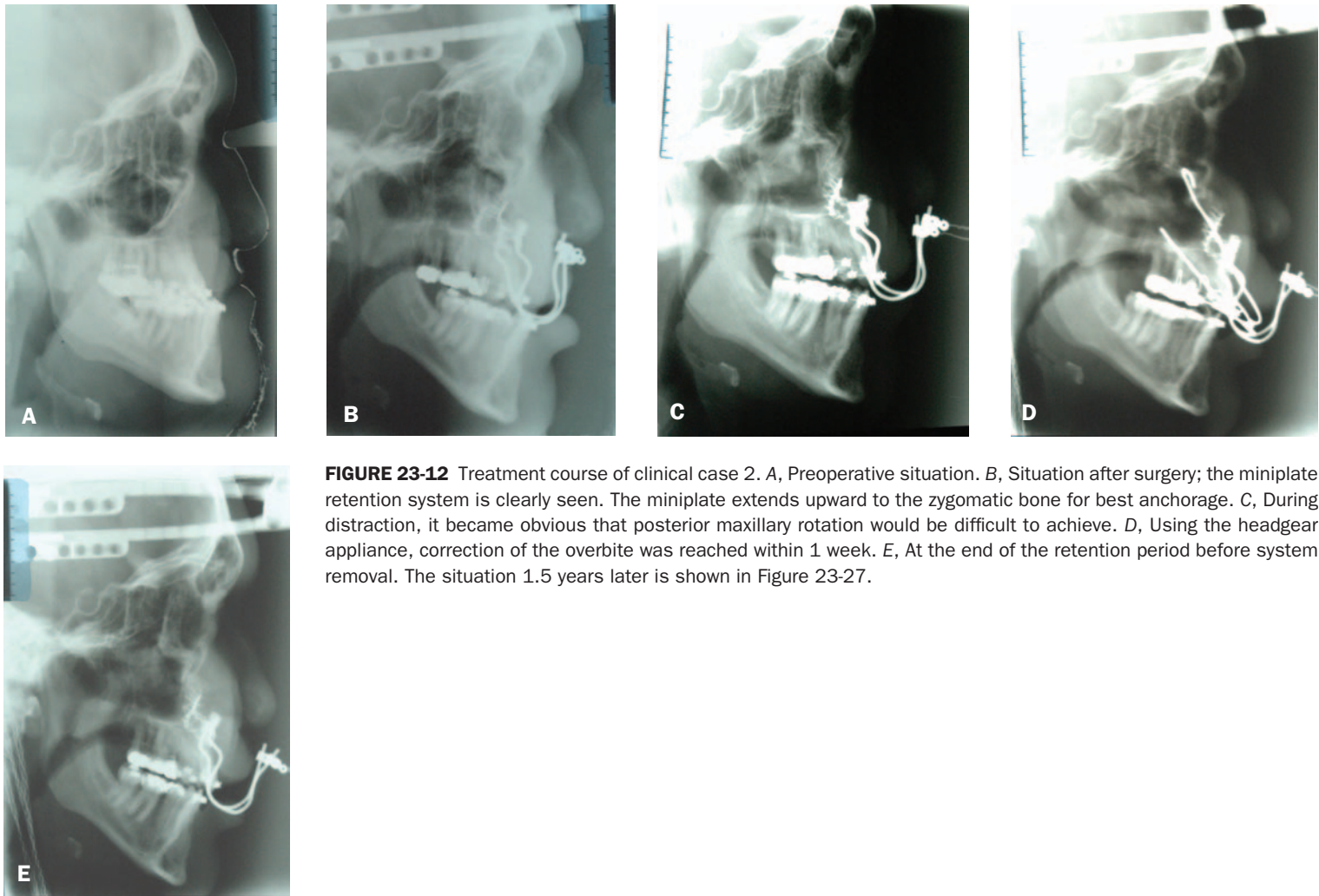


FIGURE 23-13 Preoperative sagittal scan showing the thick, scarred velopharyngeal flap. Tension caused by the flap is supposed to be one of the reasons why posterior rotation was so difficult.

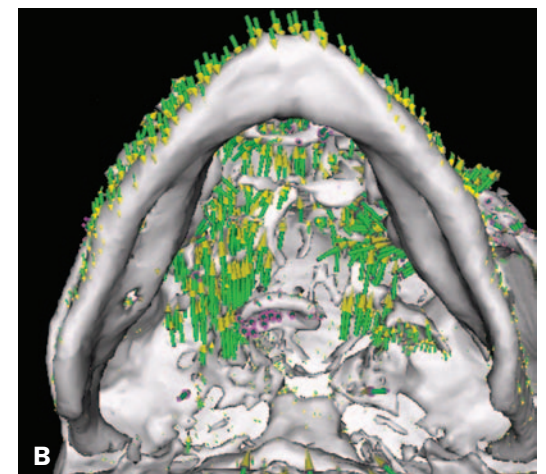
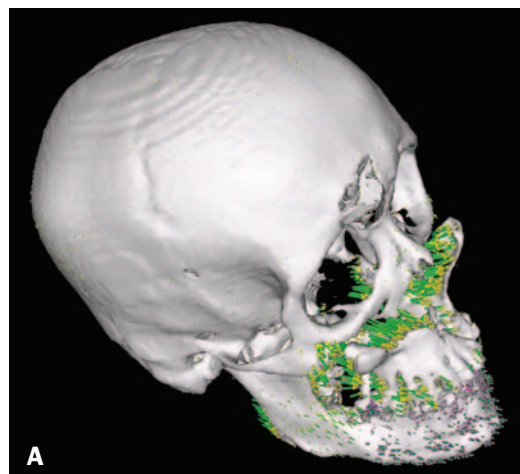


FIGURE 23-14 Displacement vectors are shown by comparing pre- and postoperative computed tomographic scans. *A*, Lateral view demonstrating the sagittal movement. Note the downward vectors in the anterior region. *B*, View from below. The left lesser maxillary segment has been moved outward as well. See the clockwise rotation of the mandible.

displacement vectors of the above-mentioned patient. The downward-directed sagittal advancement can be seen. Looking caudally, the different movements of the two maxillary segments that were not connected during distraction can be seen. The small left maxillary segment has been pulled outward to achieve an optimal dental arch. Note the downward rotation of the mandible caused by the maxillary movement.

Technique

Preoperative Diagnostics

In addition to the standard diagnostic measurements, such as lateral cephalography, orthopantomography, model casts, and photography, computed tomography (CT) is helpful in many cases for which DO is planned. On the one hand, abnormal bony or soft tissue findings may be encountered in severe retrusion cases. In 45 cases, we found 1 patient with an absent maxillary sinus, 2 patients with extreme pneumatization of the whole midface, and 10 patients with extremely thick cortical bone in the pterygomaxillary junction. On the other hand, three-dimensional imaging allows exact examination of the deficiency with perfect osteotomy planning. Furthermore, mock surgery can be performed and the amount of distraction and the necessary vectors can be seen. Using a halo frame, bony dehiscences in the calvaria are recognized easily, which might prohibit the use of these devices. Stereolithographic models have been popular for the planning of DO in some centers.¹⁰ Using proper visualization and planning software, however, the benefits of these expensive models seem questionable in most cases.

Osteotomy Design: Surgery

According to occlusal and esthetic needs, the level of the bone cuts can be freely chosen. In cleft palate patients, the standard Le Fort I osteotomy is inferior with regard to esthetics as the malar deficiency is not addressed. In our experience, a modified quadrangular osteotomy is suitable in most instances.¹¹ Starting low parasally to avoid unnecessary postoperative nasal alar flaring, the osteotomy runs inferior to the infraorbital nerve; from there it runs parallel to the infraorbital rim at the height of the infraorbital foramen. After detaching the anterior part of the masseter muscle, a 90° turn is made near the beginning of the zygomatic arch in the zygoma. The osteotomy runs down behind the zygoma and ends in the pterygomaxillary junction. This provides good malar prominence and allows simultaneous transversal widening or clockwise maxillary rotation, which would be problematic if the infraorbital rim was included. Figure 23-15 shows the pre- and postoperative CT of a typical case. If segmentation is necessary, it is done in the standard manner. All

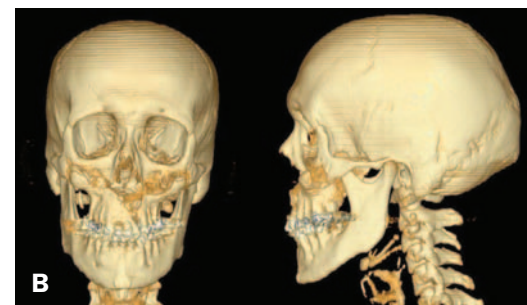
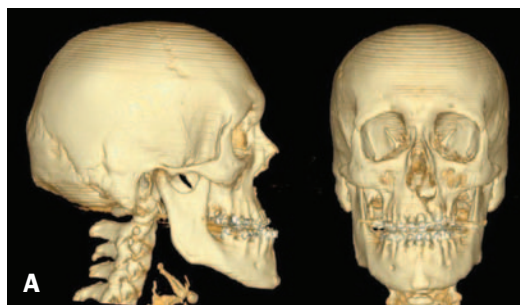


FIGURE 23-15 A, Preoperative renderings of the second clinical case. Maxillary retrusion and left-sided unilateral cleft lip and palate. B, Postdistraction scans. The maxilla has been brought forward like a drawer. The modified quadrangular osteotomy reaches the level of the lateral orbital rim. Bone grafting at the time of device removal has led to a symmetric nasal floor and augmented the nasal ala on the cleft side.

bone cuts are made from the standard intraoral vestibular incision using microjigsaws, angulated saws, and fine osteotomes. The paranasal buttress is cut, and the septum is detached from the maxilla. Pterygomaxillary separation is performed with a curved osteotome. Now the cuts are checked, and the maxilla is softly mobilized using Tessier hooks or Rowe disimpaction forceps, avoiding a downfracture. The maxilla should be slightly mobile in all directions (approximately 3–4 mm). Now the miniplates of the retention system are adapted, running from the paranasal buttress parallel to the occlusal plane and then upward along the zygomatic buttress for best anchorage. Three 1.5 mm microscrews 3 to 5 mm in length anterior to the rider and as many as possible (5–7 mm) posteriorly are inserted. Then the square 1.8 mm bar is bent to run from the rider to the canine region, into the vestibulum, and around the upper lip to end lateral at the nasal ala (Figure 23-16). Care should be taken to leave enough space to avoid compressing the lip or running too far laterally. Then the incision is

closed and a soft plastic suction tube is put over the bar (Figure 23-17). Finally, the eyelets are fixed. When performing the mucosal incision, later surgery at the time of removal of the retention plate should be kept in mind (eg, alveolar bone grafting). In bilateral cleft palate cases without previous bone grafting, the vestibular mucosa in the premaxillary region should be spared.

Now the halo frame is attached. No incisions are performed; the screws are inserted percutaneously about 3 cm superior to the auricle. The distance to the scalp should be 2 to 3 cm. The frame should be parallel to the occlusal plane, and three to four pins per side are inserted. After a soft grip has been achieved, a torque screw is suggested for final fixation (Figure 23-18). In adults, 0.3 to 0.4 nm is chosen (0.25–0.3 nm in adolescents).

Postoperative Procedure

Postoperatively, four phases must be distinguished. During the first 4 to 5 days after surgery, the torque of the halo frame is checked with a



FIGURE 23-16 Stereolithographic model with applied retention system. Three microscrews have been fixed anterior to the rider—five posteriorly. In most cases, it is better to bend the miniplate upward distally to lie on the zygomatic buttress because of the superior bone quality.



FIGURE 23-17 View of the square rods leaving the vestibulum. The rods have been covered with soft tubing. There is no inflammation at the entrance into the mucosa. Dental hygiene can be performed continuously.

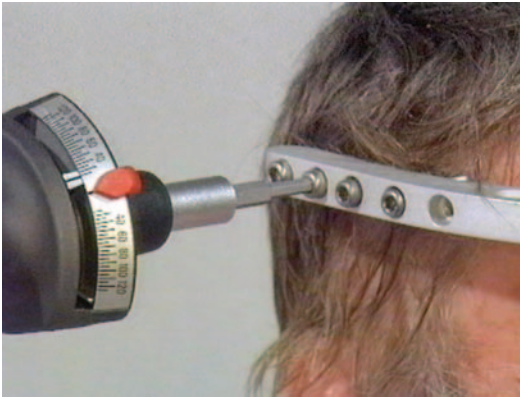


FIGURE 23-18 Use of a torque screwdriver to control pin fixation. In adults, 0.3 to 0.4 nm is suitable in most instances.

torque wrench and adjusted to the desired 0.3 to 0.4 nm in adults. On the fourth day, the vertical carbon fiber bar with the attached spindle units is fixed to the halo frame and the spindle units are connected to the retention system or dental splint. A twisted 0.4 to 0.5 mm soft stainless orthodontic wire will do. During fixation of the wire, force is slowly applied until the patient feels a soft pull. Thus, activation of the spindle units is used only for real protraction. Before that, a lateral cephalogram is taken. No antibiotics are given postoperatively; only nasal decongestants for better respiration are administered.

The second phase lasts until the end of protraction. The spindle units are turned twice a day at 0.5 mm (ie, 1 mm/d) until overcorrection is achieved. The amount of overcorrection depends on the patient's situation. In dentate adults with a good Class I occlusion after therapy, 2 to 4 mm is appropriate. In edentulous, senior cases, 4 to 5 mm is the minimum. In children, further mandibular growth must be anticipated. Even if there are formulas to calculate the final SNA° and SNB°,¹² there is no definite clue. A 4 mm overcorrection at least should be achieved as we have noticed a postoperative catch-up growth in the mandible in some cases after maxillary DO. If transversal discrepancies must be corrected, the hyrax appliance is activated simultaneously at 2×0.25 mm/d. The patient is seen once a week, and the distraction vector and halo frame are checked. After the first week, a lateral cephalogram is taken to see whether protraction is successful. It must be kept in mind that, initially, protraction may be less than 50% of the amount of distractor activation as the connecting wire is stretched. At the end of the protraction phase, advancement may be more than 1 mm/d as the energy "saved" in the bent external bar of the retention system or dental splint is given back. Thus, there might still be some protraction even if the spindle units are no longer turned. Chang-

ing of the distraction vector should be done in small increments during the weekly visits. In the rare cases in which more distraction length is needed and the distractor can no longer be activated, the following procedure can be recommended. Two 5 mm steel rods are bent in an "S" manner and threaded on one end. They are fixed with nuts on both sides of the halo frame, and the eyelets of the retention system or splint are wired to the anterior end until the patient notices the pull. Then the spindle units can be turned back and reconnected to the retention system. Now the two provisional rods can be dismounted and distraction started anew (Figure 23-19).

The third phase is the retention period. The duration lies between 3 and 8 weeks and depends on the patient's age and dentition and the treatment procedure. In children and young dentate adults, at least 3 weeks in an overcorrected situation are performed; the older and less dentate the patient, the longer the period should be. In our senior patients, 8 weeks is recommended. The patients are seen every 10 to 14 days, and the distractor and occlusion are checked. Light elastics might be used if a slight open bite is seen. In cases of a marked anterior open bite, a headgear might be used, as described before. Furthermore, criss-cross elastics are employed to correct transversal misalignments and a transpalatal archwire to widen or constrict the maxillary arch.

At the end of the retention period, the device is removed. Using the miniplate retention system requires surgery with general anesthesia, but this is no drawback in most instances. In cleft palate patients, alveolar bone grafting with cancellous bone is performed; in edentulous patients, a sinus lift is done to allow later implant placement. Light elastics are worn for at least 4 weeks. A Delaire-

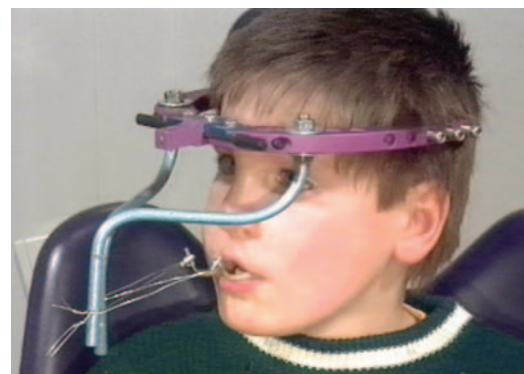


FIGURE 23-19 Reactivation of the spindle units. Two custom-made steel rods have been fixed to the halo frame. The retention system is attached to them with wires, and the vertical bar with the spindle units has been removed for demonstration purposes. The spindle units are turned back and refixed to permit further protraction. The two custom-made rods are then removed.

style face mask may be used for retention, but most patients dislike the pressure on the chin and forehead. If in doubt, it is advisable to remove the distractor 1 week later as the halo frame is more comfortable than the Delaire mask. Regarding the time of distractor removal, two treatment options can be chosen. If excellent occlusion can be reached, the retention time could be longer to allow best bony consolidation (up to 8 weeks). If there are some minor discrepancies in any direction, a more dynamic regimen is preferable. Here overcorrection in a sagittal direction must be at least 3 mm, and the distractor is removed after 3 weeks if a good overbite has been achieved. Then elastics are used to guide the maxilla slowly back into proper occlusion while further bony consolidation proceeds.

A final point must be stressed. During maxillary protraction, it is extremely important to watch the vectors and watch for complications. It is suggested that one surgeon should take care of the patient throughout the whole treatment period to see the changes that occurred.

Morbidity

DO is a technically demanding procedure with a higher complication rate than conventional orthognathic therapy.¹³ In addition to the use of complicated devices, patient cooperation is crucial. In our own first series of 35 patients, 7 patients (19%) had to undergo a second operation owing to technical problems (loosening of the halo frame, insufficient intraoperative mobilization, loosening of the retention system, premature bony fusion, incorrectly positioned bar of the retention system). In the following 10 cases, no reoperation owing to technical problems occurred, demonstrating the learning curve of a new procedure. Considering the postoperative position of the midface, three subsequent Le Fort I procedures were necessary in 45 cases. In the first case (shown in the section on vector control), the postoperative open bite had to be corrected. In one case, the 16-year-old patient suddenly went on vacation during treatment and activated the distractor 14 days too long (ie, 14 mm), resulting in gross overcorrection. The device was removed instantly, and elastics were applied; 6 months later, the maxilla was set back with a 1 cm osteotomy of the distraction area. In the last case, a three-segment distraction was performed. At the beginning of therapy, however, it was obvious that a final Le Fort I procedure would be necessary after bony consolidation of the 18 mm advancement. Using extraoral appliances, infection has not been a problem. When a dental splint is used to protract the maxilla, temporary increased dental mobility may be encountered. In our first six cases in which dental splints were used, one deciduous molar was fully extruded and six permanent teeth elongated, which had to be intruded afterward. From then

on, dental splints were abandoned. Considering all postoperative complications, a three to four times higher rate might be initially encountered. It must be kept in mind, however, that a 25 mm distraction of an edentulous maxilla in a 65-year-old cleft palate patient is a different procedure than a standard 6 mm Le Fort I advancement; thus, comparison of complication rates is somewhat arbitrary.

Pain may be encountered in senior patients or in cases of heavy soft tissue scarring. Administration of muscle relaxants and logopedic treatment (muscle activation and relaxation techniques and massages) are helpful. If the pain is not relieved, a reduction in the distraction rate to 0.5 mm/d for some days may be helpful.

Costs

Costs are one of the major problems in DO as all of the single-use devices are expensive. As device costs differ from country to country and from hospital to hospital, only general statements can be made. Considering that the halo frame will be reused (depending on legislative restrictions), some parts, such as the carbon fiber rods, must be replaced after three to four treatments. The pins and the retention system are definitively single use; thus, hardware costs are three to five times more expensive than four miniplates in Le Fort I procedures (the costs of the halo frame have not been included).

Time of Treatment and Surgery

The time of surgery in DO is similar to that in conventional orthognathic procedures. As the time of the osteotomy is dictated by the appropriate level, there should be no differences. In our own experience, however, osteotomies last longer as we have moved from Le Fort I to modified quadrangular bone cuts in DO, which take more time. A time-saving benefit in DO is that there is no necessity for IMF and wiring of splints, whereas fixation of the retention plates takes the same time as miniplating the four buttresses. The time saved for IMF is, however, needed for halo-crown fixation afterward.

The time of treatment in DO is comparable when considering that miniplates will be removed after conventional procedures. There is a longer period of outpatient visits in DO, and controls are more time consuming as the distraction vector and halo-crown fixation must be checked.

Outpatient Feasibility

In addition to surgery, DO using the above-mentioned technique is ideally suited for outpatient treatment. As full mobilization and downfracture of the maxilla are not performed, there is significantly less swelling and hematoma.

Furthermore, there is no need for intermaxillary fixation, allowing free oral respiration. Patients can move around on the ward on the first postoperative day, and no antibiotics are administered postoperatively in our department. It is possible to dismiss the patient until the fourth postoperative day, when the distractors are attached to the halo frame and the patient is instructed. Then the patient is seen once a week until the end of protraction.

Case Reports

The first case is a 13-year-old boy suffering from cleft palate and midfacial retrusion. Figure 23-20 shows the overclosure of the mandible and the marked malar deficiency. After maxillary distraction, good facial convexity is seen. Lip balance improved instantly, and logopedic therapy, which was almost impossible before treatment, could now be performed (Figure 23-21). Figure 23-22 shows the situation at 15 years. The facial dimensions and occlusion are stable.



FIGURE 23-21 Situation 1 month after removal of the halo frame. Good facial convexity and lip competence.

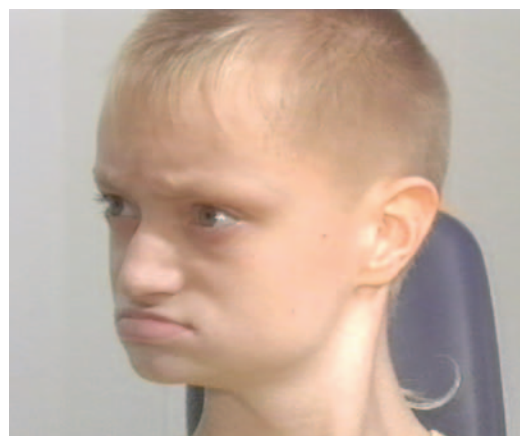


FIGURE 23-20 A 13-year-old boy prior to distraction osteogenesis. Marked maxillary hypoplasia with an overclosed mandible. Class III can be seen on the lateral cephalogram.

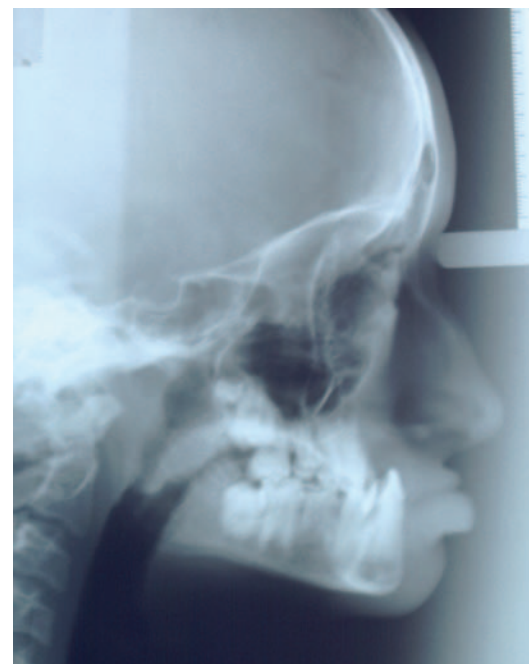




FIGURE 23-24 Class III occlusion (the corresponding lateral cephalogram is shown in Figure 23-12A) preoperatively.

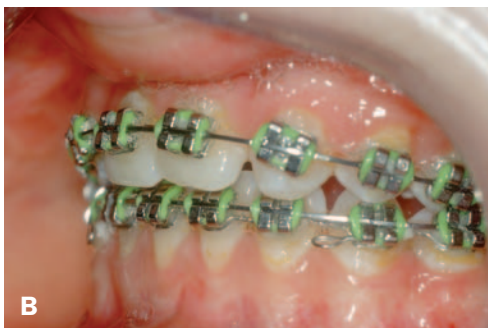


FIGURE 23-22 Same patient at 15 years. A, Lateral view showing esthetic improvement. C and D show lateral cephalogram and occlusion at that time.

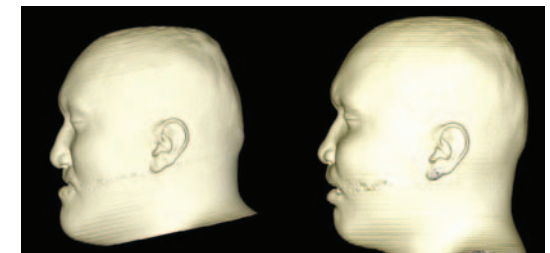


FIGURE 23-25 Surface rendering of the pre- and postoperative situations (15 mm advancement) showing improved malar prominence, uprightened nose, and facial fullness.

The second case is a 23-year-old male student with unilateral cleft lip and palate and maxillary deficiency. Figures 23-23, 23-24, and 23-12A show the preoperative situation and the lateral cephalogram. The preoperative CT situation was shown in Figure 23-15A. After a modified quadrangular osteotomy, the maxilla was advanced in two separate pieces to allow adjustment of the maxillary arch. During treatment, it became obvious that the open bite would be difficult to close (see Figure 23-12C), so a headgear was applied (see Figure 23-11). The final cephalogram shows the situation before device removal (see Figure 23-12E). Postoperative CT demonstrated the advancement of the maxilla. At the time of device removal, alveolar cleft bone grafting and paranasal augmentation were performed (see Figure 23-15B). Surface reconstruction of the CT scans shows the change in facial appearance (Figure 23-25). The situation 1 year later is shown in Figure 23-26. Finally,



FIGURE 23-23 A 23-year-old man suffering from unilateral cleft lip and palate and marked facial concavity.



FIGURE 23-26 Situation 1 year after distraction osteogenesis. The facial convexity is still good.

Figure 23-27 shows the results after nasal surgery 1.5 years after DO. There is a Class I occlusion with a pleasing esthetic appearance and good facial convexity. Advancement was over 15 mm, and no subsequent velopharyngeal incompetence was seen (a preoperative velopharyngeal flap was present).

Case 3 is a 55-year-old male patient with unilateral cleft lip and palate. He was referred to our department because sufficient prosthetic dental therapy was impossible (Figures 23-28 and 23-29). After removal of the remaining two periodontally insufficient maxillary teeth, the maxilla was advanced 20 mm and the large alveolar cleft

bone was grafted with cancellous bone from the hip at the time of device removal after 12 weeks of retention. Simultaneously, a sinus lift was performed bilaterally, and the distraction gap, which showed no bony dehiscences, was stabilized with four miniplates on the paranasal and zygomatic buttresses. Three months later, dental implants



FIGURE 23-27 Same patient as in Figures 23-12, 23-23, and 23-26 one and a half years after distraction osteogenesis and after final nasal surgery. Situation seen before bracket removal. Class I occlusion has been maintained. An acceptable outcome at the end of treatment.



FIGURE 23-28 Preoperative situation of a 55-year-old male patient with unilateral cleft lip and palate: marked midfacial concavity, two teeth left in the maxilla, and a large oronasal fistula.



FIGURE 23-29 Preoperative lateral cephalogram.



FIGURE 23-30 Lateral cephalogram 1.5 years after distraction osteogenesis. Stable Class I situation with inserted implants in the maxilla (magnetic abutments).

were incorporated into the maxilla and the miniplates were removed. Two and a half years after DO, a full prosthetic rehabilitation with pleasing esthetic outcome was evident (Figures 23-30 and 23-31). The scars of the halo-frame pins are virtually invisible. The preoperative existing velopharyngeal incompetence increased; thus, a velopharyngeal flap was raised 1 year after surgery. An interesting fact is that mandibular setback surgery had been performed 20 years earlier in this patient.

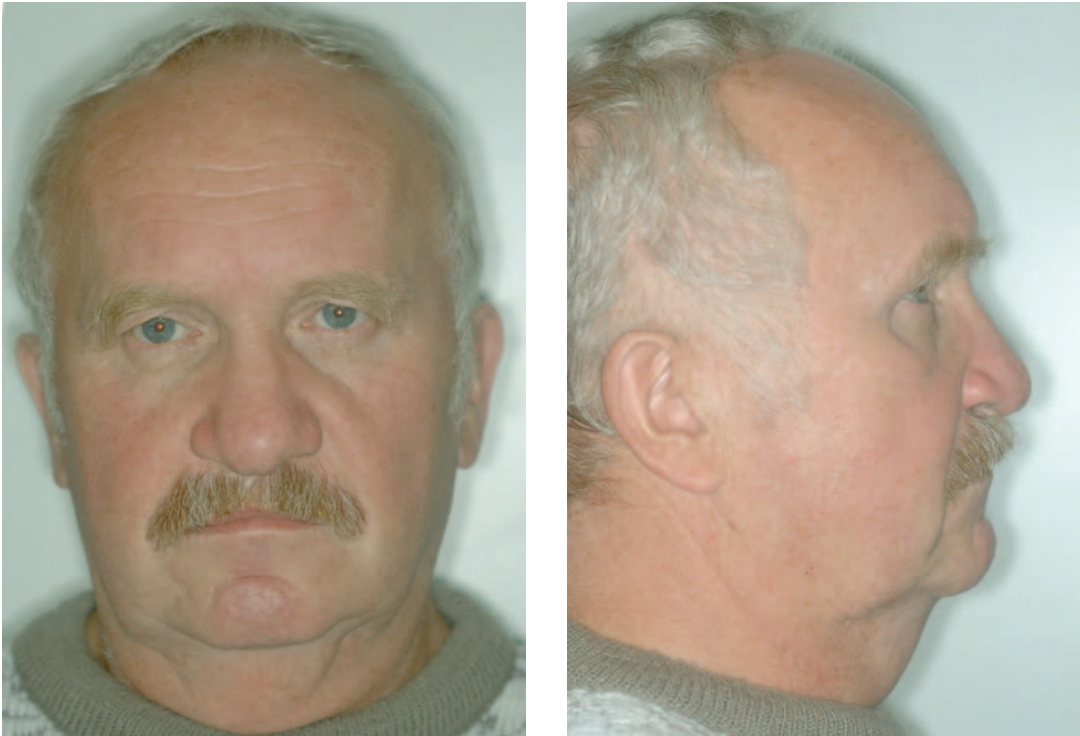


FIGURE 23-31 Photograph 2.5 years after distraction osteogenesis. The esthetic outcome is pleasing; the scars of the halo-frame pins are virtually invisible. The facial appearance has changed totally.

Acknowledgments

The DICOM data used for the 3D-rendering and for the calculation of the displacement vectors were kindly supplied by the Department of Orthodontics, Leipzig University. All

orthodontics seen was done at the Department of Orthodontics, Leipzig University. Software development for the calculation of displacement vectors was done by Gerd Wollny, Max-Planck-Institute for Human Cognitive and Brain Sciences, Leipzig, Germany.

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Gradual Repositioning of the Midface at the Subcranial Le Fort III Level by Distraction Osteogenesis

G. E. Ghali and Douglas P. Sinn

Indication

Distraction osteogenesis for severe (> 10 mm) midfacial deformities is preferred over immediate movement (orthognathic) osteotomies. The deformities that might be included for this type of treatment are patients with cleft-associated or syndrome-associated midface hypoplasia, such as Apert, Crouzon, and Pfeiffer syndromes (Figure 24-1).¹ Other patients with severe hypoplasia of the midface including the orbits, nose, and maxillary regions are also ideal candidates for

this technique.² These types of deformities are not uncommon, and the syndromic deformities alone can occur in 1 in 10,000 births.³ This chapter is limited to midface distraction at the subcranial or extracranial Le Fort III level. In our practice, we use one of the three major subcranial Le Fort III osteotomy designs depending on the desired aesthetic goals (Figure 24-2). Of the three major designs, we find the modified Tessier I (vertical zygomatic split) to be our most preferred and often used choice based on the improved postoperative result at the lateral orbital rim.

Advantages

There are several considerations regarding the indication for distraction, including the magnitude of the deformity and the ability to create a movement that is adjustable during the distraction process.⁴ The stability associated with significant deformities that require movement greater than 8 mm without bone grafting is also indicated for distraction. Immediate correction of deformities beyond the 10 mm range is compromised by stability issues and generally requires primary bone grafting with skeletal fixation to manage the inherent instability associated with these large movements.⁵ In contrast, distraction offers a scenario in which bone grafts are not required and the magnitude of movement can predictably be three to four times greater than is otherwise achievable.^{6,7} Adjustments can be made in the anterior-posterior and vertical planes. Correction of asymmetries via variable distraction techniques is possible. Multilevel distraction can be achieved with differential movements, including separation at the Le Fort I level, moving the maxilla a predictable amount forward, and simultaneously with further appliances creating variable advancements of the malar area, with or without naso-orbital components. Devices are available for either external or internal distraction depending on the surgeon's preference.⁸ We prefer to use external distractors for Le Fort III level distractions.

Disadvantages

The disadvantages associated with this technique are of some concern. These disadvantages include the following: the required use of internal or external stabilization or distraction devices, required construction of hardware appliances that may need to be prepared on a pretreatment basis to attach to the maxillary teeth for movement at the Le Fort I level, required hardware removal (excluding resorbable distractors), less

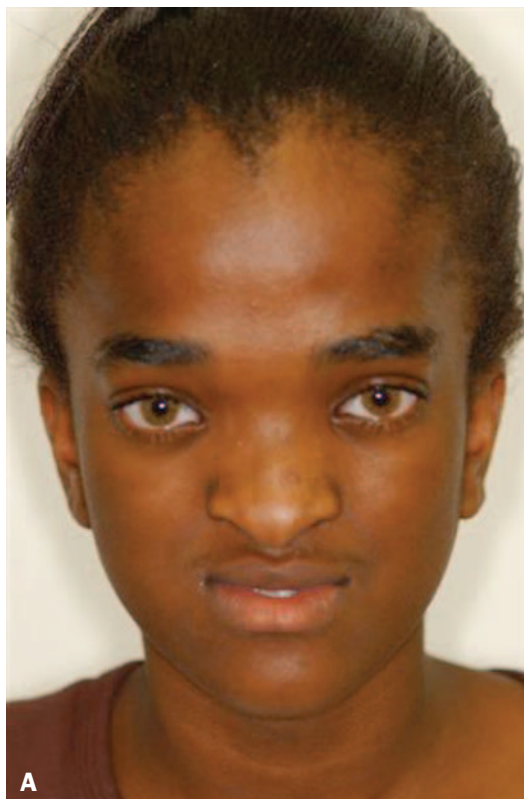


FIGURE 24-1 Patient with a typical facial deformity benefiting from midface distraction at the subcranial Le Fort III level. She required 14 mm advancement. A, Preoperative frontal view. B, Preoperative profile view.

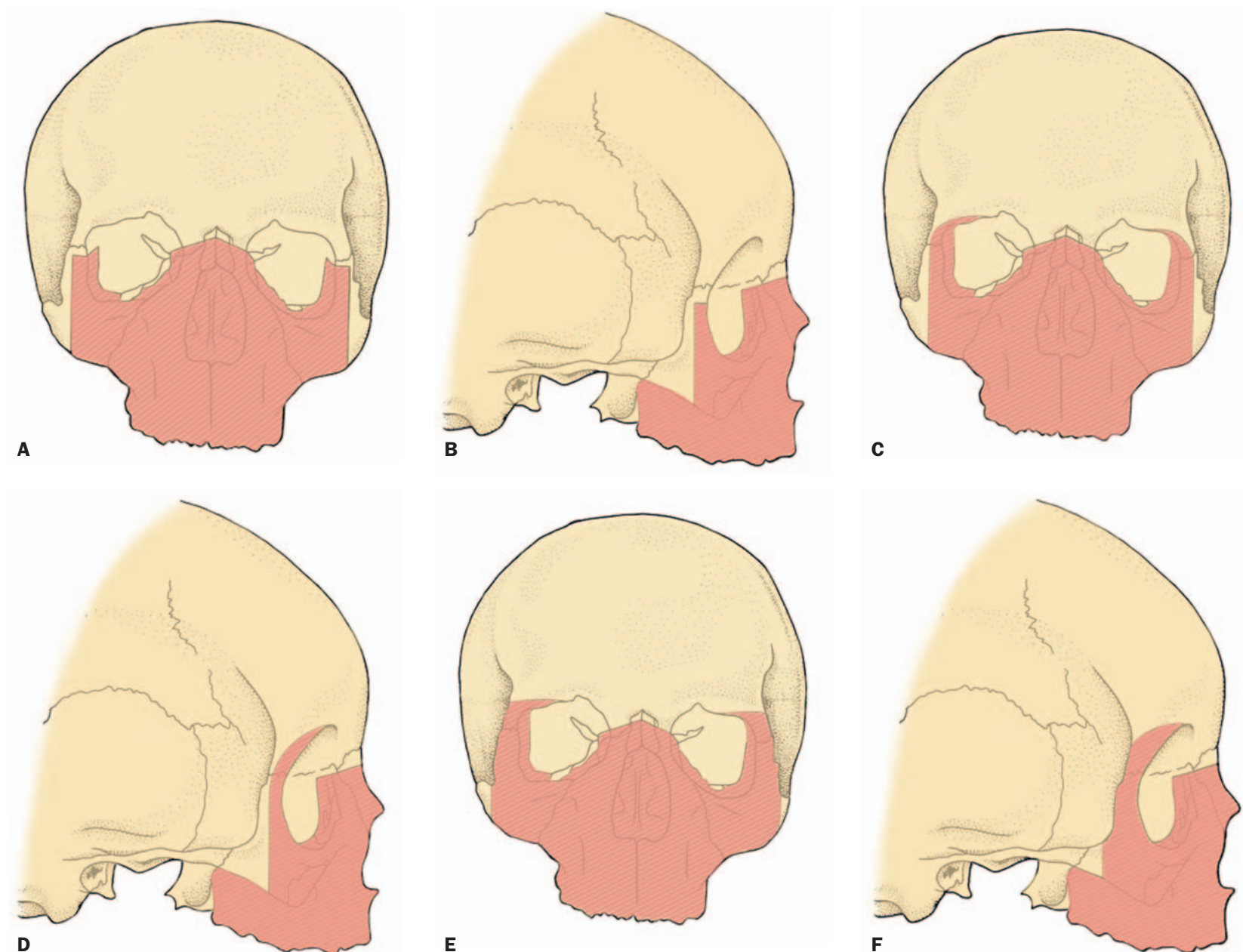


FIGURE 24-2 Anterior and lateral views of subcranial Le Fort III osteotomy designs. A and B, Tessier I. C and D, Modified Tessier I (vertical zygomatic split). E and F, Tessier II.

predictable vector control, possible need for pre-operative orthodontic interventions when indicated, and multiple procedures may be required. Additionally, some degree of alopecia could result at the site of scalp pin placement.

Vector Control

The horizontal plane of distraction is determined by the vector applied. One should position the device to accomplish the goals needed to create the exact vector of movement. Orthodontic preparation and its role in vector management are very important to achieve the correct outcome. Tooth movement in a consolidated dental arch controlled by orthodontic appliances is crucial

to success in most cases of maxillary or midface distraction.

Morbidity

Morbidity is directly related to the age of the patient. Developmental tooth position is the most significant morbidity associated with external devices and is related to technique. Osteotomies that are required for mobility of the maxillary or midfacial components at any and all levels have an inherent risk to the dentition. Particular dangers to the permanent teeth, growth plates, and sinuses are of significant concern. Blood loss is usually minimal and in normal circumstances is not a major issue. Injury to sensory nerves is

common, but recovery to the preoperative state is the norm within 8 to 12 months. Care must be exercised to prevent nerve injury. Infection is uncommon but can occur locally around distraction devices as they exit through the skin or oral mucous membranes. Relapse is not common if the consolidation of the regenerated bone is complete. Growth after distraction is minimal; therefore, apparent relapse may be from lack of growth in the regenerated bone or growth of a nondistracted area (ie, the mandible).

Cost

Usually two procedures are required rather than one owing to the need for hardware removal.

Although the overall cost is less from a hospitalization standpoint (no bone grafts), considering the materials required, including devices for accomplishing the goal, the cost is similar.

Timing of Treatment and Surgery

This is related primarily to the magnitude of the deformity. Surgery should be early for patients with severe deformities to reduce the deformity during growth spurts before and after puberty (Table 24-1). Coordination of procedures with the specific needs of the patient and the treating orthodontist is critical to success. Many of these children will be unable to undergo formal orthodontic treatment prior to or during this initial distraction phase owing to a lack of permanent tooth anchorage. Most will require definite orthognathic surgery and/or orthodontic therapy at an age-appropriate time.

Treatment includes a surgical procedure for application of the appliance followed by a latency period and then activation of the appliance. At the conclusion of distraction, which is usually within 10 to 14 days, a consolidation period is required, which can last from 30 to 90 days postoperatively. After the consolidation period, it is necessary to remove the device and finalize the position of both the osseous and the dental segments in conjunction with orthodontics. Total treatment time, excluding postoperative orthodontics, is probably 90 days, but if you include preoperative and postoperative orthodontics, it could be up to a year or longer.

Outpatient Feasibility

It is possible to complete Le Fort I osteotomies, application of appliances, and distraction in an outpatient setting. The morbidity of bleeding, although present, is reduced considerably because of the reduced amount of mobilization that is normally required. Osteotomies completed at the Le Fort II or III level have a higher morbidity rate and are not recommended on an outpatient basis. Most frequently, these patients require 1 to 2 days of hospitalization for management of fluids and blood loss associated with upper level Le Fort osteotomies.

Subcranial Le Fort III Maxillary Osteotomy: Step-by-Step Approach

Step 1: Anesthesia and Preparation

Oroendotracheal intubation is preferred, and the tube is secured with wire adjacent to the incisal edge of the mandibular central incisors or is sutured to the labiomental fold region. In the minority of cases, if the patient is to be placed into maxillomandibular fixation, nasoendotracheal intubation is preferred. Hypotensive anesthesia is recommended, with a mean arterial pressure between 50 and 60 mm Hg. Additionally, two units of packed red blood cells are held for use if needed. Tarsorrhaphy sutures are placed bilaterally with 6-0 nylon for ocular protection. The patient's head is placed in a pediatric Mayfield head rest in the neutral position for maximal exposure of the neck, face, and anterior scalp (Figure 24-3). The head and neck region is then prepared and draped in a sterile fashion. Sterile towels are stapled into position for optimal exposure. Following formal preparing and draping of the patient but prior to incision, the external distraction device is preadapted and completely assembled prior to placement. General guidelines for subcranial Le Fort III external distractor placement are as follows: (1) adjust the transverse width of the device, allowing the lateral arm to extend wider than the scalp or hair by 2 cm

bilaterally; (2) the halo should be aligned parallel to the Frankfort horizontal plane with the vertical bar component approximately 3 cm anterior to the upper lip; (3) hand-turn the cranial screws sequentially bilaterally until bone is contacted on a minimum of four screws per side; and (4) place the two horizontal bars at the desired vector of anterior distraction corresponding to the distraction plates and/or intraoral appliance. Following preadaptation, the assembled external halo device is carefully removed and placed on a sterile table for final adaptation at the end of the procedure.

Step 2: Coronal Approach

A coronal incision is preferred. Lidocaine (0.5%) with epinephrine (1:200,000) is injected in the proposed site of incision to facilitate hemostasis. In many patients, there is a coronal scar from a previous cranial vault remodeling procedure. In such cases, it is essential to be very careful during flap elevation because it is not uncommon to have areas of dura exposed without overlying bone. In most midface advancements, we prefer to place the incision well within the hairline toward the vertex but anterior enough to allow adequate exposure of the temporozygomatic region. Not uncommonly, the coronal incision needs to be extended slightly in a preauricular or postauricular direction for additional exposure. The initial incision is made through scalp skin and galea with

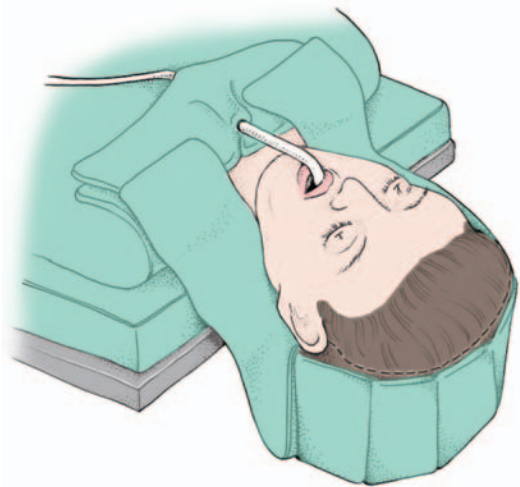


FIGURE 24-3 Anesthesia and preparation.

Table 24-1 Timing of Distraction Surgery	
Deformity	Distraction Timing
Crouzon's syndrome	First decade
Apert's syndrome	
Pfeiffer's syndrome	
Cleft lip and palate	After alveolar graft and expansion complete (first decade)
Nasal/maxillary/malar hypoplasia	Second decade with major orthodontic input

a blade (Figure 24-4A). Raney clips are applied for hemostasis, and cauterization is minimal to reduce injury to hair follicles (Figure 24-4B).

Step 3: Flap Reflection

The initial dissection of the anterior scalp flap is in a suprapariosteal plane, with an incision made through the periosteum (pericranium) approximately 2 cm above the supraorbital ridges. The supraorbital nerve may require release from its bony canal with a 2 mm osteotome. Careful sequential subperiosteal dissection allows visualization and exposure of the nasal dorsum, lateral orbital rims, anterior maxilla, and zygomatic arches. A tunneling technique is used to achieve exposure of the nasal bones, medial canthal tendons (MCTs), superior aspect of the lacrimal fossa, and medial and inferior orbital margins (Figure 24-5A). In most cases, medial dissection is carried within the orbit down to the nasolacrimal groove, without disruption of the MCTs. Circumferential subperiosteal dissection around the orbit should allow mobilization of the periorbital so that the inferior orbital fissure is clearly visualized and the osteotomy may be located approximately 10 mm inside the orbital margin. A tunnel should generally be created connecting the medial and lateral subperiosteal dissection. The zygomatic arch and temporal fossa are exposed in a bilateral fashion by division of the deep temporal fascia approximately 5 cm superior to the arch and is reflected inferiorly

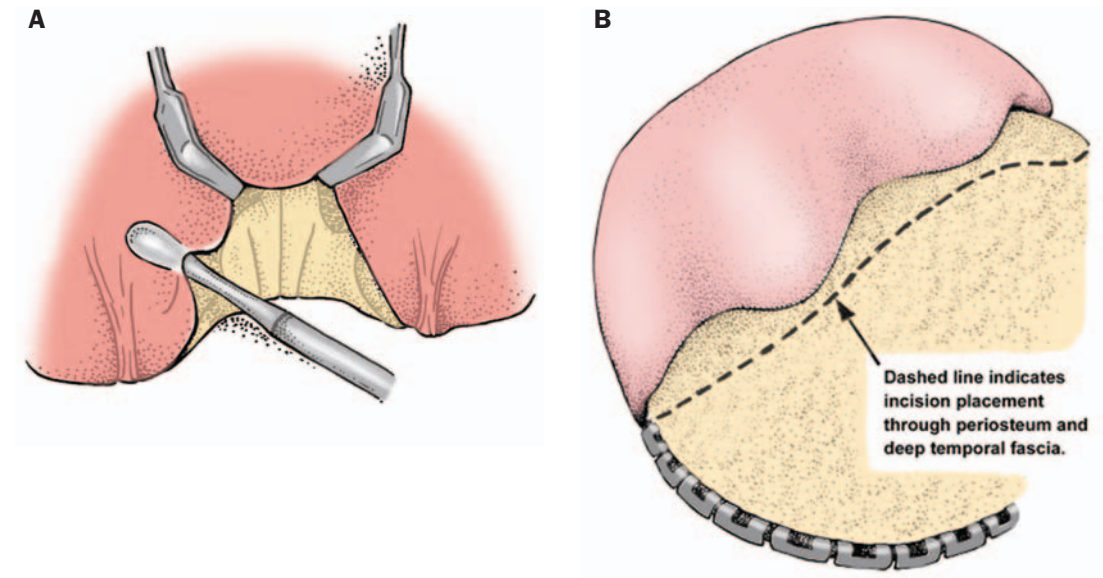


FIGURE 24-5 Initiation of the anterior scalp flap. A, Tunneling technique for exposure of the dorsum, medial orbital region, and orbital floor posterior to the nasolacrimal apparatus. B, Subfascial dissection to the zygomatic arch.

while maintaining attachment to the coronal flap (Figure 24-5B). The soft tissue envelope is progressively reflected off the lateral orbital rim and zygoma toward the maxilla via gentle stretching using periosteal elevators. Throughout the flap reflection, bone is used as a guide to prevent

injury to the frontotemporal branch of the facial nerve.

Step 4: Osteotomies

The first osteotomy is the zygomatic osteotomy via a vertical cut at the body of the zygoma using

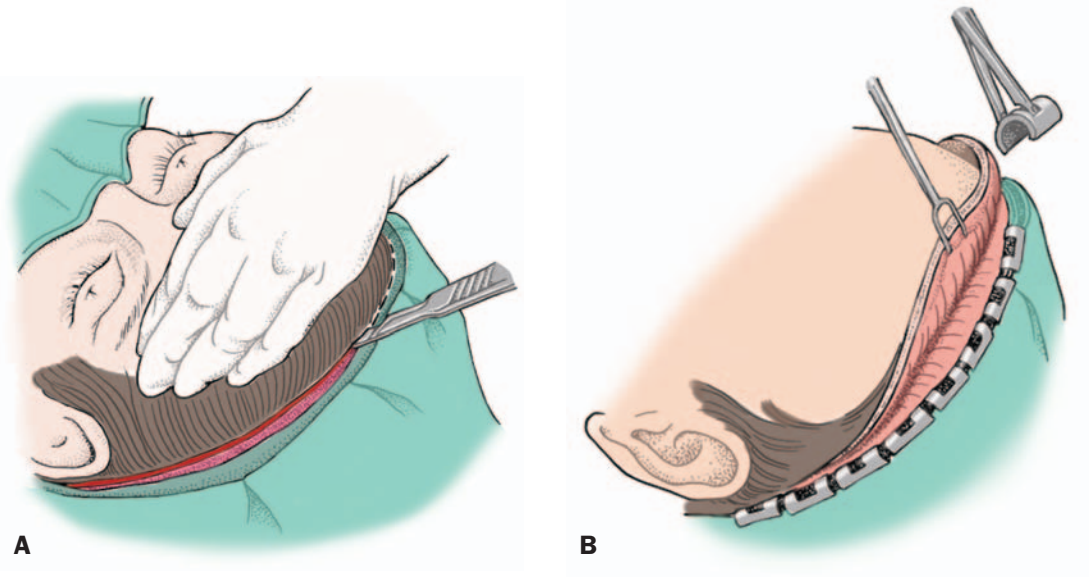


FIGURE 24-4 Typical coronal approach. A, Skin and galea incised with a blade, stopping just superficial to the pericranium. B, Raney clips are applied to the wound edges.

a reciprocating saw. It is designed so that it extends from the bottom of the zygoma, splitting the lateral orbital rim in half and extending superiorly to end slightly above and medial to the frontozygomatic suture (Figure 24-6A). The identical osteotomy on the contralateral side should be made parallel to the first osteotomy and ideally perpendicular to the vector of distraction (ie, Frankfort horizontal plane). With careful globe protection, the lateral orbital wall osteotomy is initiated 10 mm behind the lateral orbital rim via a reciprocating saw through the inferior orbital fissure, extending superiorly to meet the initial osteotomy superior to the frontozygomatic suture (Figure 24-6B). From the inferior orbital fissure via a supratemporal fossa approach, the posterior wall of the maxillary sinus is cut posteriorly and

inferiorly (via an osteotome) or posteriorly and superiorly (via a reciprocating saw) from the superior half of the pterygomaxillary junction. After both right and left lateral osteotomies are completed, attention is directed to the medial osteotomies. Prior to initiating the horizontal nasal osteotomy, as well as the subsequent separation of the bony nasal septum from the anterior cranial base, coronal computed tomographic scans are reviewed to verify the position of the cribriform plate. The horizontal osteotomy extending over the nasal bones is completed 5 mm inferior to the nasofrontal suture via a reciprocating saw in a direction posterior-inferior and superior to the MCTs and nasolacrimal apparatus (Figure 24-6C). Attention is then turned to the medial orbital osteotomies. After finishing the

nasal bone cut posterior to the lacrimal fossa, the direction of the osteotomy is behind and parallel to the posterior lacrimal crest as it moves toward the inferior orbital fissure; a 6 mm osteotome is generally used to complete this step (Figure 24-6D). The nasal septal osteotomy is used to separate the nasal septum from the cranial base. The direction of the osteotomy is parallel to the base of the skull and directed toward the posterior nasal spine as palpated transorally (Figure 24-6E). The inferior half of the pterygomaxillary junction is separated bilaterally using a curved pterygoid osteotome approach via the temporal fossa (Figure 24-6F). An alternative approach would be via an intraoral route with a limited vestibular incision bilaterally. We find the latter helpful in situations in which adequate mobilization is difficult without an inferior vector of traction.

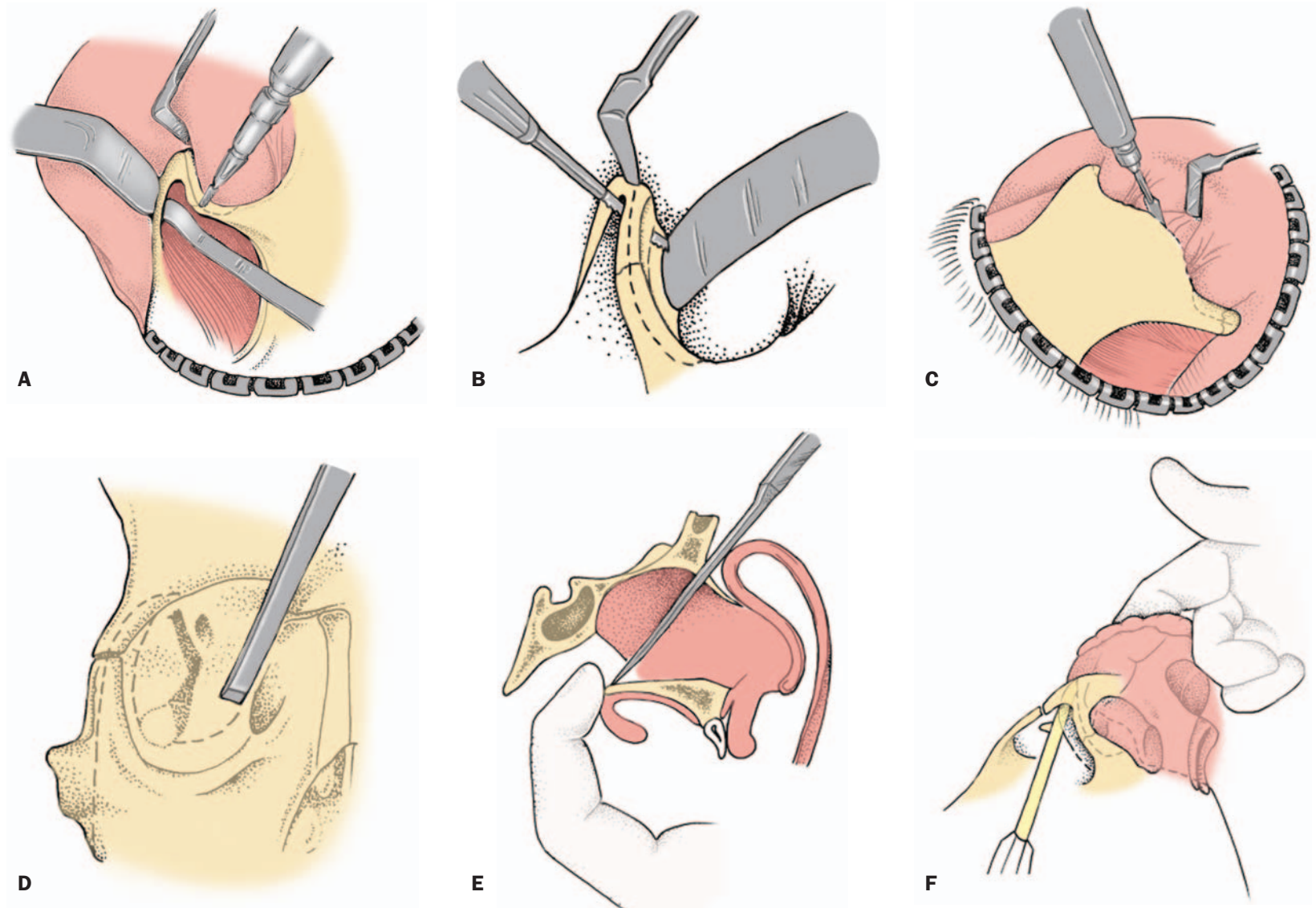


FIGURE 24-6 Superior temporal view of the zygomatico-orbital region. A, Osteotomy through the zygomatic arch bisecting the lateral orbital rim. B, Lateral wall osteotomy through the inferior orbital fissure. C, Horizontal nasal osteotomy. D, A 6.0 mm osteotome is used to extend the cut across the medial wall and orbital floor. E, Separation of the bony nasal septum from the anterior cranial base. F, Osteotomy of the pterygomaxillary suture with a curved osteotome through a coronal incision.

Step 5: Midface Mobilization

Maxillary disimpaction forceps are applied to mobilize the midfacial segment until the planned distance is reached without excessive tension (24-7). This is achieved with gentle rocking and traction. Initially, one should ensure that the midface is moving in one piece by inspection. Care must be taken to avoid excess traction on the orbital neurovascular structures or excessive unilateral traction on the zygomas, resulting in fracture.

Step 6: Closure and Final Distractor Placement

The mobilized midfacial unit is repositioned prior to wound closure. In most cases, we prefer to replace the midface and stabilize it bilaterally in its original position with 3-0 plain gut suture drilled and secured above and below the fronto-zygomatic level suture region. This helps prevent displacement during the 1-week latency period and ensures reinitiation of periosteal growth without a gap between osteotomy sites. The coronal and any intraoral wounds are irrigated with a saline solution. The deep temporal fascia is repositioned with a 3-0 slow resorbing suture, and the coronal flap is redraped over the skull. A single 10 mm flat suction drain is placed under the scalp flap and positioned carefully to avoid entrapment by the cranial screws of the external distractor. The coronal flap is closed in a standard

two-layered fashion. The subcranial Le Fort III requires four points of fixation at two separate vertical levels to achieve optimal multivector distraction. In children old enough to have banded orthodontic appliances placed, an additional vector of guidance is achieved by using elastic band therapy concurrently to guide the midface into a more favorable occlusion. Distraction attachment plates (three to four) serve as bone fixation points for the distraction wires attaching to the external device. The attachment plates are typically placed bilaterally in the infraorbital rim region as bone and erupting dentition permit via a 1 to 2 cm transcutaneous incision and are secured with four 1.5 mm screws. Additionally, it has become our preference to place an attachment plate with space for two threaded fixation screws at the piriform aperture in proximity to the anterior nasal spine (Figure 24-8). All threaded

fixation screws are 2.0 mm in diameter and are available in 15 and 25 mm lengths. They have a hole for threading the wire and are secured to the 1.5 mm attachment plates after drilling. The threaded fixation screws are brought out through the skin and the surrounding skin closed in a single layer with 6-0 nylon suture. The external halo distractor is replaced as discussed in step 1, tightened appropriately, and attached to the four threaded fixation screws with 24- or 26-gauge stainless steel wire.

Step 7: Distraction Protocol and Removal

Following a latency period of 7 to 10 days, distraction is initiated at 1 mm per day. This is usually divided into 0.5 mm in the morning and 0.5 mm in the evening. Adjustments in the vector can be made at any time via alterations in the position of the horizontal bars or variations in the rate of distraction on one side compared with the other. The consolidation period is usually three to four times as long as the period of distraction. The attachment plates are generally left in place, and the threaded fixation screws are removed, along with the external halo component, under general or local anesthesia.

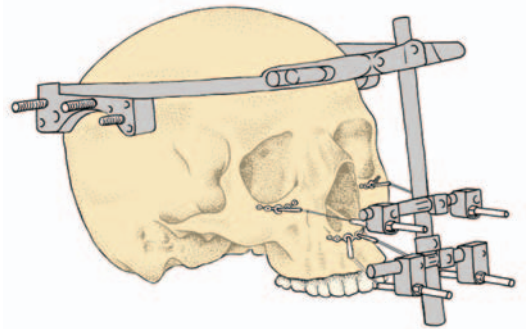


FIGURE 24-8 Multidirectional external device demonstrating the ideal position of the osteotomies, attachment plates, and halo for a subcranial Le Fort III osteotomy and distraction procedure.

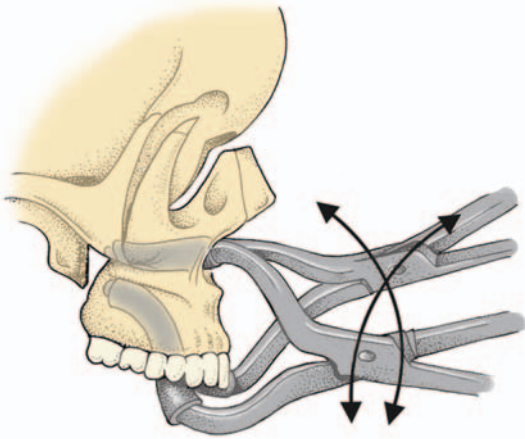


FIGURE 24-7 Midface mobilization with disimpaction forceps using gentle traction.



FIGURE 24-9 Postoperative frontal (A) and lateral (B) views following subcranial LeFort III distraction.

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Combined Push-Pull Midface Distraction Osteogenesis

Bonnie L. Padwa

Patients with syndromic craniosynostosis typically have diminished orbital volume, midfacial hypoplasia, and upper airway obstruction. Tessier's classic Le Fort III osteotomy and midfacial advancement increase orbital volume, improve facial profile, and open the upper airway.¹ However, the soft tissues often limit the magnitude of movement using the traditional procedure, and there is the additional morbidity of harvesting interpositional bone grafts, which are needed to maintain and bridge the bony defects after the midface has been advanced. Distraction osteogenesis allows the soft tissues to be gradually stretched and permits greater midfacial advancement without the need for bone grafting.

Fearon reported that midfacial advancement using the technique of distraction osteogenesis is three times greater than that obtained with conventional osteotomy and bone grafts.² He found that midfacial movement, measured as horizontal change at the A point and upper incisal edge, was 19 mm for the distraction group and 6 mm for the standard single-stage group. Similarly, Chin and Toth reported a mean increase of 20 mm (range 16–30 mm) measured at the infraorbital rims in nine patients with midfacial hypoplasia corrected by distraction.³

Following Le Fort III (subcranial) osteotomies (Figure 25-1), the midfacial segment can be distracted by either pushing it forward, using semiburied devices, or pulling it forward by a rigid external device.⁴⁻⁷ For each method, there are inherent technical difficulties relating to the control of vectors of movement, symmetry of advancement, and differential movement of the upper or lower face. There are also differences in patient compliance and comfort during distraction with these two types of devices.

The RED system (KLS Martin L.P., Jacksonville, FL.), originally designed by Polley and Figueroa for Le Fort I advancement,⁸ uses a dental-borne appliance for traction. It is easier to control the vector(s) in three planes by midfacial pulling with the rigid external device (RED). However, there can be unequal advancement of the upper and lower midface using this halo-type

device, particularly when a dental-borne appliance is used to draw the midface forward. This pull-type device was subsequently modified (RED II) by adding rigid plates secured to the infraorbital rims with transcutaneous wires to improve control of the movement at the infraorbital region and upper midface. However, the infraorbital transcutaneous wires cause scarring, at right angles to the relaxed cutaneous tension lines, in a prominent part of the face. More recently, bone-retained traction hooks that can be secured to the anterior maxillary wall have been used to help obviate the problems with both the dental-borne appliance and use of transcutaneous wires (Figure 25-2). There have been several problems related to the pins used to affix the halo to the cranium, such as temporal scarring, cerebrospinal fluid leakage, depressed skull fracture (after a fall),⁹ and even death resulting from migration of a fixation pin.¹⁰ The RED device is bulky and not well tolerated by many patients, particularly older children and adolescents.

In contrast, semiburied push-type devices are designed to push the midfacial complex forward (Figures 25-3 through 25-6). These devices have the advantages of being unobtrusive and without the obvious pin or wire tract sites. However, they are not without their limitations.

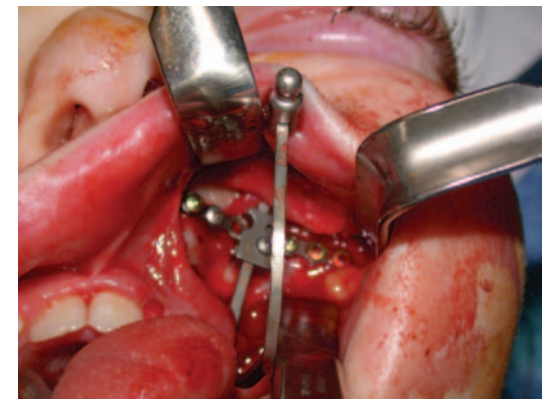


FIGURE 25-2 Bone-retained traction hooks are secured to the anterior wall of the maxilla at the infraorbital rims to allow the midface to be pulled at a level higher than the dentition.

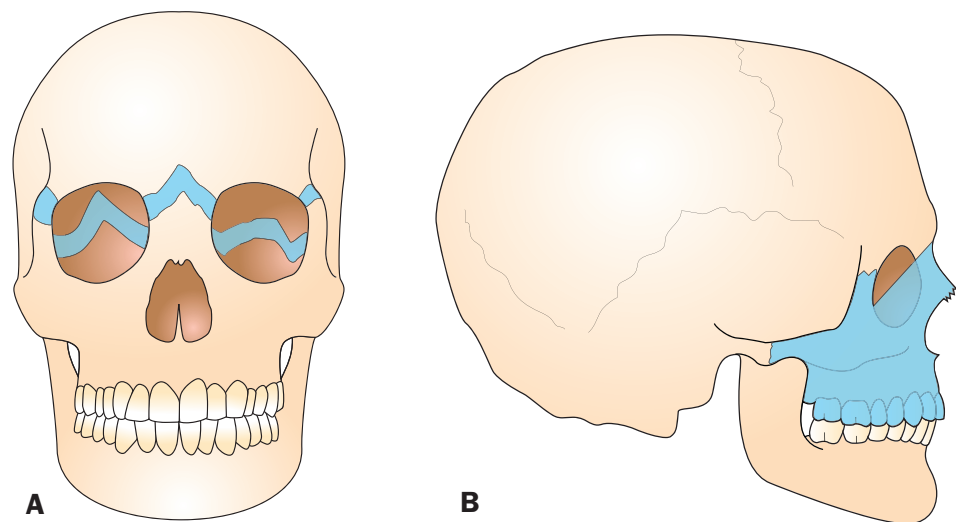


FIGURE 25-1 Standard subcranial Le Fort III osteotomy is performed, and the midface is mobilized.

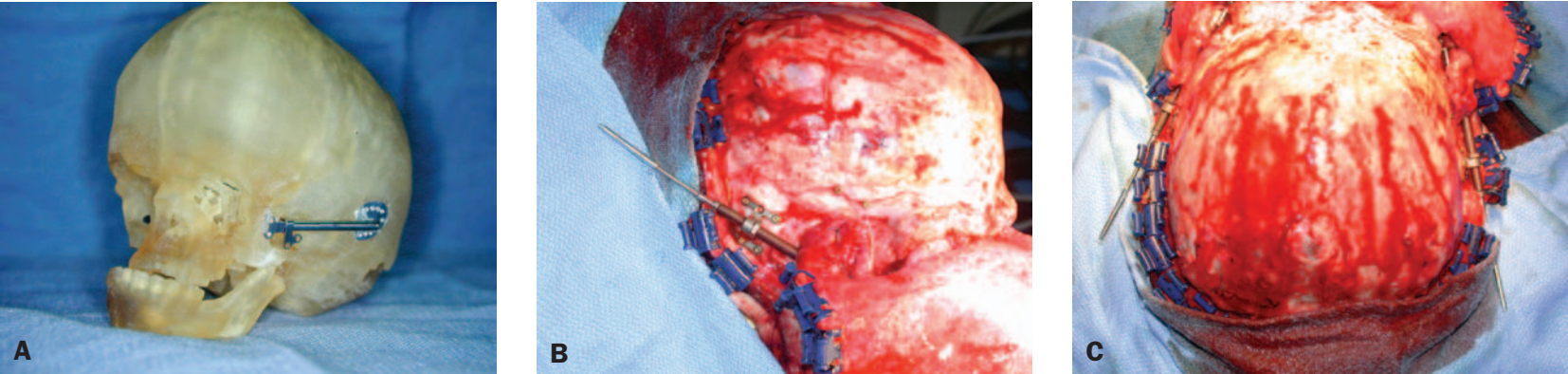


FIGURE 25-3 A to C, Semiburied distraction devices (Synthes, CMF, Westchester, PA.) are placed deep to the temporalis muscle and secured proximally to the temporal bone and distally to the lateral orbital rims below the frontozygomatic osteotomy. The devices are placed as parallel as possible to one another to control advancement in the coronal and horizontal planes.



FIGURE 25-4 The turning element is passed percutaneously, posterior to the coronal incision, and is used to activate the expansion screw to advance the upper portion of the midface.

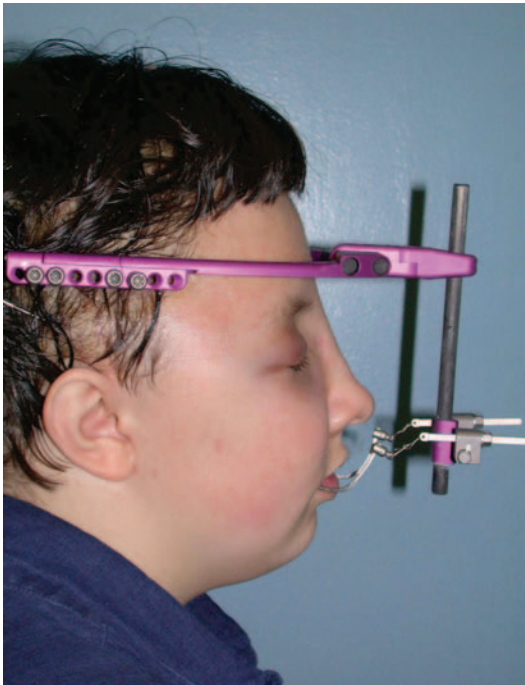


FIGURE 25-5 After the coronal incision is closed, the rigid external distraction device (RED) is secured to the cranium using three to four percutaneous screws per side. The device is positioned 3 to 4 cm above the superior border of the helix on each side with the device parallel to the Frankfort horizontal plane. Twenty-six-gauge traction wires are connected from the external hooks of a rigid intraoral splint or a bone-retained plate to the activating screws located on the horizontal bar of the device.



FIGURE 25-6 Postoperative lateral cephalogram shows the position of both the push (semiburied) and pull (rigid external) distraction devices.

For a normal midfacial profile, the infraorbital rims, nasal root, and maxillary dentoalveolus must be advanced in concert. The semiburied devices fail to control the anterior-inferior vectors during the active phase of distraction.¹¹ Gosain and colleagues documented that the extent of midfacial movement at the occlusal level, using semiburied (push type) devices, was 10 mm less than that recorded at the infraorbital rims.¹¹ This discrepancy is caused by rotation of the midfacial segment wherein the zygomaticomaxillary complex moves further anteriorly than the dentoalveolus. This occurs because it is difficult to locate the push devices inferior enough to translate the force of distraction at the dental level. To correct sagittal disharmony in patients who needed differential advancement, Satoh and colleagues reported simultaneous Le Fort III and I midfacial distraction using an internal device for the upper portion of the midface and an external device for the lower midface.¹²

Other potential problems with the internal distraction method are either asymmetric movement of the midface or inadequate advance-

ment of the central midface. Fearon used semiburied devices in only two patients and documented slightly greater advancement on one side than on the other, which occurred despite attempts to correct this during active distraction.² Push-type distraction by bilateral buried devices also can exaggerate facial concavity because of relatively greater advancement laterally at the zygomatic arches and zygomaticosphenoid sites. Fearon also underscored this point, stating that the profile would be better if distraction involved pulling at the facial midline rather than pushing from the sides with buried devices.² For the same reason that semiburied devices fail to advance the central midface, there is the potential for fracture at the zygomaticomaxillary junctions. The internal devices translate the anterior force to the midface through the body of the zygoma, which is weak at the zygomaticomaxillary junction in patients with syndromic craniosynostosis. As a result, this juncture can fracture during distraction, resulting in failure to adequately advance the pyramidal segment.^{11,13} Because of this complication, Gosain and colleagues devised several ways to alter the distraction protocol.¹¹

The modifications included changing from an internal to an external distraction system, rigid fixation and bone graft stabilization of the midface, or plate stabilization of a fractured or unstable zygomaticomaxillary junction followed by resumption of internal distraction.

The pushing and pulling type of appliances have their own advantages and disadvantages. However, there are benefits to using them together, and their weaknesses are not additive. The combined technique provides the benefit of "belt and suspenders," in case one appliance fails. The external distraction device can be removed at the end of the active distraction phase, and the internal device is adequate to maintain the advancement during the consolidation period. More importantly, push-pull distraction permits equal movement at both the upper and lower facial levels, advancement of the central midface, and symmetric movement of the zygomaticomaxillary complexes. The push-pull distraction technique is a simple solution until a better single device is devised (Figures 25-7 through 25-9).



FIGURE 25-7 A, Preoperative frontal and lateral photographs of a 5-year-old girl with Pfeiffer syndrome. She has a Chiari I malformation and significant midface retrusion with exorbitism and obstructive sleep apnea. B, A lateral cephalogram demonstrates midfacial hypoplasia. C, Frontal and lateral photographs during the consolidation period 5 weeks after Le Fort III osteotomies and placement of distraction devices. The obstructive sleep apnea has resolved. D, A lateral cephalogram during the consolidation period shows the advanced midface. A dental-borne appliance has been used with the rigid external distraction device. E and F, Frontal and lateral photographs and a lateral cephalogram 1 year after midfacial advancement using the push-pull distraction technique shows the midface to be in a good position.



FIGURE 25-8 A, Pre-operative frontal and lateral photographs of a 9-year-old girl with Apert syndrome. She has significant midface hypoplasia and obstructive sleep apnea. B, Ten days after Le Fort III osteotomy and placement of semiburied (pushing) and rigid external (pushing) distraction devices. C, One year after midface advancement using the technique of distraction osteogenesis, there is an improved midfacial position and the obstructive sleep apnea has resolved.



FIGURE 25-9 A, Preoperative frontal and lateral photographs of a 14-year-old girl with Muenke syndrome who had late fronto-orbital advancement at age 7 years. B, A lateral cephalogram demonstrating “push” and “pull” distraction devices. C, One-year postoperative frontal and lateral photographs show an improved midfacial position. She will need correction of upper lid ptosis and rhinoplasty.

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Alternative Treatment Strategies to Bimaxillary Surgery

Dale Bloomquist

Orthognathic surgery treatment planning has many times in the past been limited by the surgical techniques available and not by diagnostic limitations. A good example was the generalized use of mandibular surgeries in the treatment of Class III malocclusions prior to 1970. This was the case even though maxillary osteotomies, especially the Le Fort I, had been discussed in the literature and been in use, especially in Europe, since the 1950s. Only after some experience was developed in a few major teaching centers in the United States was the Le Fort I osteotomy considered, either by itself or in conjunction with a mandibular procedure, for the treatment of these malocclusions. Another difficulty in orthognathic treatment planning has been the limitations of not having universally accepted and research-proven diagnostic criteria for maxillofacial deformities. Although a number of diagnostic regimens have been suggested, the sheer number of different criteria that have been discussed suggests the difficulties that exist in this area. Two skeletal relationships that appear to have the least agreement about the diagnostic criteria are anterior open bites and transverse discrepancies between the maxilla and mandible. Traditionally, these deformities were treated with at least a maxillary osteotomy and many times required bimaxillary surgery. Other options in dealing with these deformities now exist owing to the development of the midsymphysal or midline osteotomy and rigid internal fixation. Recent experience with^{1,2} and research³⁻⁵ in these procedures has resulted in giving the oral and maxillofacial surgeon the option in certain situations to limit the surgery to the mandible alone. Limiting the surgery to the mandible must be done only when the surgeon can be assured of obtaining excellent facial esthetics and at the same time expect stable skeletal and dental results.

Mandibular Midline Osteotomy

The mandibular midline osteotomy is used, with the bilateral sagittal split osteotomy (BSSO), most

commonly for narrowing the mandibular arch to prevent a posterior crossbite. There are two clinical situations in which this can be used. The first, and most common, occurs when the mandible is being advanced, and because of differences in arch form, a mild posterior crossbite develops (Figure 26-1). Orthodontists often have difficulties in correcting this transverse discrepancy, and especially in the adult patient, these corrections can be unstable. The second situation for which the mandibular midline osteotomy may be considered is with a mild maxillary constriction. This should be considered only when the maxillary constriction has minimal, if any, negative esthetic effect. Again, the orthodontist has limited resources to deal with this constriction, and the traditional surgical methods of using a surgically assisted rapid maxillary expansion or a Le Fort I osteotomy obviously entail much more surgery.

Criteria

The mandibular midline osteotomy should be used only in situations in which there needs to be 10 mm or less of constriction measured at the second molars. As mentioned earlier, there should be no significant esthetic problems with the maxillary arch form. Although there are minimal, if any, esthetic consequences of narrowing the mandible, the surgeon should avoid this procedure in individuals with noticeably narrow mandibles. It is important to understand that there will be minimal change in the width of the mandible at the canines. It is beneficial to explain this to the orthodontist so that changes in the axial inclination of the canines can be made, if necessary, prior to surgery. There is generally no other need for special orthodontic preparation, although the central incisor roots must be at least parallel, if not divergent. The orthodontist should constrict the mandibular arch wire 1 to 2 days before the surgery to remove any possibility of dental relapse.

Technique

Care should be taken during the model surgery to avoid removing any plaster from the mesial aspect of the crowns of the incisors between which the cut is to be made. This will avoid difficulties in fitting the surgical splint since the point of rotation of the narrowing appears to be at the level of the cingulum of the incisors. Rarely is there any separation between those teeth. There is a mild lingual tilting of the segments during the tightening of the teeth into the splint, so it is wise to overcorrect the molar cusp position by 1 to 2 mm. The amount of overcorrection will depend on the axial inclination of the posterior teeth before surgery. This overnarrowing will allow the orthodontist to correct the axial inclination of the posterior teeth and provide for any relapse. Although, generally, relapse is minor with this procedure, it is easier for the orthodontist if given this room to finish.

The mandibular midline osteotomy follows both sagittal splits and is made easier if the mandible is stabilized by wiring in the surgical splint. Normally, only one side of the mandibular arch will fit into the splint; the opposite side will be stabilized enough to avoid difficulties during the bone cut. The mucosal incision needs to be only about 1.5 cm, and the periosteum is elevated from the attached tissue to about 0.5 cm above the inferior border. A thin blade on a sagittal saw is used to make the bicortical cut from the inferior border to just above the apices of the teeth. A monocortical cut is then continued to the level of the attached tissue. The split is completed by a prying action with a thin instrument, usually an osteotome. Avoid malleting the osteotome, which can displace the teeth from the splint. The teeth can then be fully seated in the splint and the intermaxillary wires tightened. There is no need to cut the orthodontic arch wire because this wire assists in the stabilization of the fragments. The four-hole fixation plate should be carefully bent to establish as neutral a fit as possible. The plate should be placed at least 5 mm below the apices of the teeth



FIGURE 26-1 Patient with bilateral sagittal split osteotomy and midline osteotomy. Pretreatment photographs (A–F) and cephalogram (G–I) surgery model setup before midline osteotomy demonstrating the cusp to cusp molar relationship.

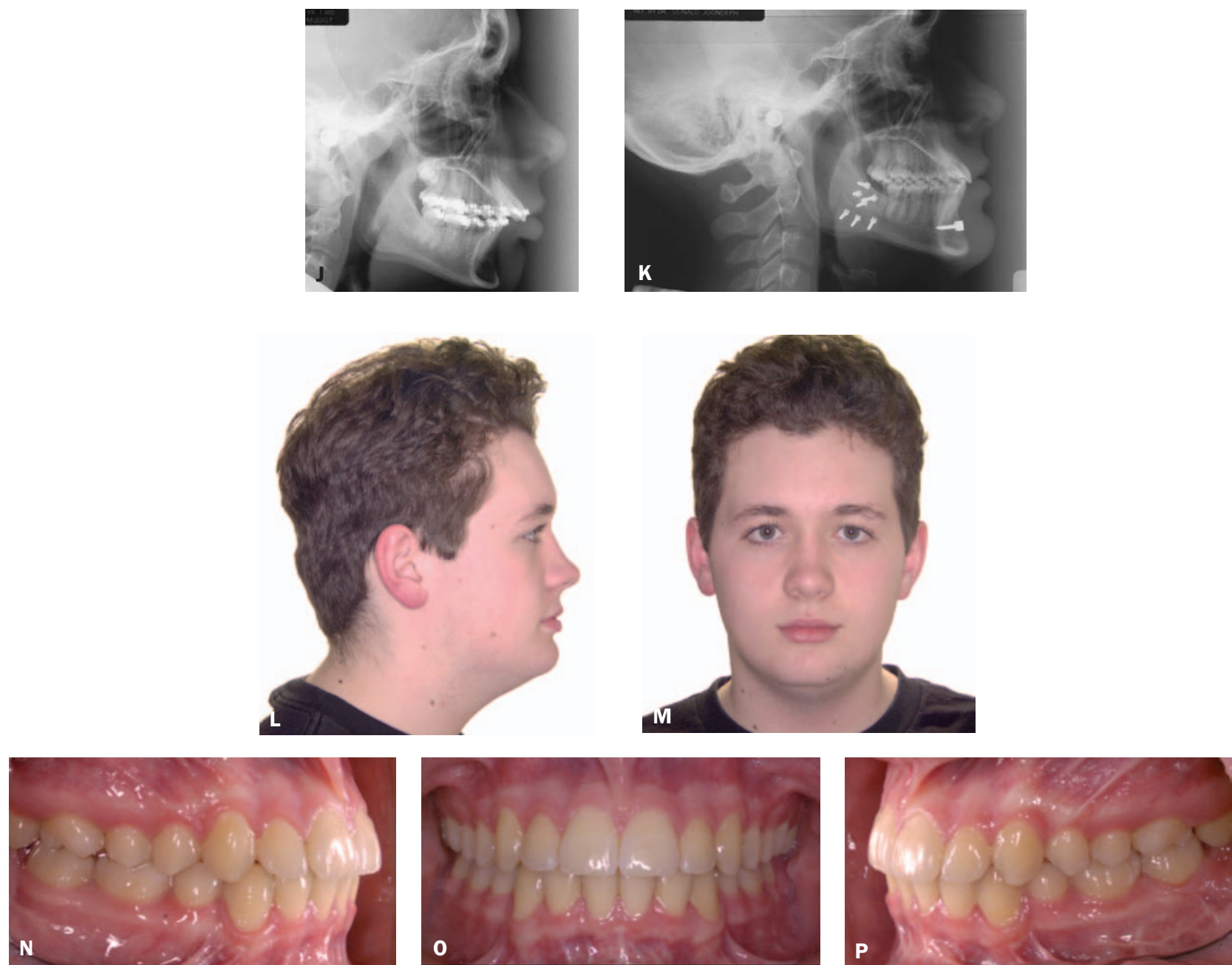


FIGURE 26-1 Continued *J*, Presurgery head film; *K–O*, final photographs; and *P*, final cephalogram.

and fixed with bicortical screws. Two plates are sometimes used, especially when there is thin cortical bone.

An alternative technique can be used when a horizontal osteotomy would be beneficial to the patient. In this situation, the horizontal osteotomy is completed first and then the midline cut is made again, with the bicortical cut completed only to a point just above the apices of the incisors (Figure 26-2). The teeth are completely seated

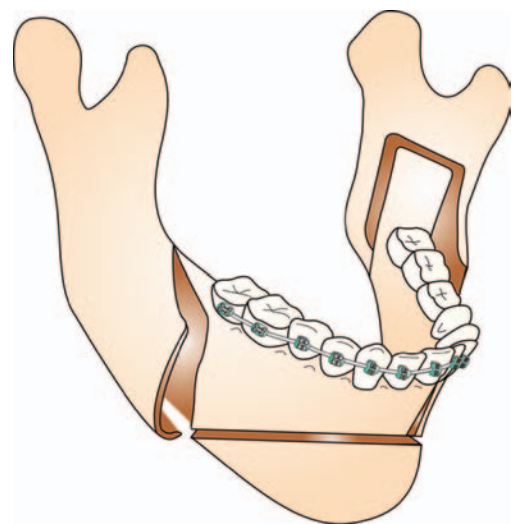


FIGURE 26-2 Midline osteotomy combined with horizontal osteotomy.

into the splint and fixed with the intermaxillary wires. The inferior free fragment is then used as the fixation “plate” by placing four bicortical screws, two screws for each mandibular segment (Figure 26-3).

The main limitation of this technique is having sufficient anterior mandibular height to allow the horizontal cut and screw placement without endangering dental apices.



FIGURE 26-3 Patient with bilateral sagittal split osteotomy and both midline and horizontal osteotomies. A–E, Pretreatment records; F–J, final records; K, postoperative panoramic radiograph.

Closing an Anterior Open Bite with the Sagittal Osteotomy

Traditionally, anterior open bites have been surgically treated by clockwise rotation of the maxilla or by maxillary segmental osteotomies in which the posterior segments are intruded and/or the anterior segment(s) are extruded. Surprisingly, the research literature for these maxillary osteotomies has demonstrated only 50 to 70% long-term success. These findings are complicated by the fact that in many patients, there is a compromise in the esthetic results. Given that the etiology of anterior open bites is still unclear, the justification of only using maxillary osteotomies has generally been attributed to the high relapse rate of using mandibular osteotomies that was seen in the era of wire osseous fixation. The use of rigid internal fixation has opened the possibility of treating this deformity with a mandibular osteotomy (Figure 26-4). Although the research literature in this area is limited, there is now sufficient clinical experience, along with available research, to support closing anterior open bites using mandibular osteotomies with rigid internal fixation.

Criteria

Attempts at establishing diagnostic criteria for skeletal open bite have noted that abnormalities exist in both the mandible (short posterior ramus, steep mandibular plane) and the maxilla (increased posterior maxillary height, level maxillary occlusal plane). Given that these features often all exist at the same time, the decision on which jaw to move is difficult to make based on cephalometric normal values alone. There are also no research data to help in that decision. Thus, often this decision is made on the well-known esthetic effects of clockwise rotation of the maxilla and counterclockwise rotation of the mandible. Upper lip form and axial inclination of the maxillary incisors are extremely important in deciding whether the surgery should be done in the maxilla or mandible. Closing an anterior open bite with maxillary surgery always will result in uprighting of the incisors and often a flattening of the upper lip. The position of the chin point relative to the mandibular incisors is important to consider in mandibular surgeries because the

chin will become more prominent with this rotation.

The need for changes in other planes of space may also play a significant role in deciding which jaw will be used to close the open bite. Since patients with an open bite may exhibit some vertical maxillary excess, simple vertical intrusion of the maxilla may correct much, if not all, of the open bite without negative soft tissue effects. The use of the mandibular midline osteotomy allows correction of minor transverse discrepancies at the same time as closing an open bite with a mandibular BSSO.

The one important criterion that must be met before a surgeon can use a mandibular osteotomy to close an open bite is a level maxillary occlusal plane. In some instances, this may be difficult, if not impossible, for the orthodontist to accomplish, and in those cases, a maxillary segmental osteotomy needs to be done. However, the concern of many orthodontists, as well as surgeons, that leveling the maxillary occlusal plane before surgically closing an open bite will build in instability has been shown to be unfounded.



FIGURE 26-4 Closure of an anterior open bite with a mandibular bilateral sagittal split osteotomy. A–E, Pretreatment records; F, preoperative cephalogram; G–K, final records; L, postoperative cephalogram.

Technique

There is no special technique to closing an open bite using a mandibular BSSO except for achieving adequate internal rigid fixation. Using four 2 mm–diameter bicortical screws on each side has been found to provide more stability than three screws. There have not been any reports of experience on using plates or larger screws for internal fixation in closing open bites. As should be standard with closing open bites with maxillary osteotomies, the surgeon should ensure that there is a greater than normal anterior overbite

with incisal contact at the completion of surgery. Depending on the presurgical orthodontic preparation, this, in some instances, may result in some posterior open bite. Posterior open bites are often easy for the orthodontist to correct, whereas gaining a more anterior overbite after surgery may be next to impossible.

Often an anterior open bite exists with a relatively narrow maxilla in relation to the mandible. As was mentioned earlier, in those cases in which the maxillary constriction is minimal, a mandibular midline osteotomy can be used so that the surgery can be limited to one jaw.

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Bilateral Sagittal Ramus Osteotomy versus Distraction Osteogenesis for Mandibular Advancement: Argument for Conventional Orthognathic Surgery

Myron R. Tucker and Brian B. Farrell

During the last 50 years, a variety of osteotomy designs have been described for correction of mandibular deficiency. Early surgical techniques incorporated an extraoral approach to the ramus and a wide variety of osteotomy designs. These osteotomies were usually done in combination with bone grafting, and the jaws were stabilized with maxillomandibular fixation. The bilateral sagittal ramus osteotomy (BSRO), done through an intraoral approach, has become the procedure most frequently performed by oral and maxillofacial surgeons for correction of mandibular deformities. Refinements in surgical technique and the addition of rigid internal fixation have significantly decreased the morbidity of this procedure and provided satisfactory results in the surgical correction of a wide variety of mandibular abnormalities.

Over 20 years ago, initial reports of distraction osteogenesis (DO) opened a new frontier for corrective surgery in long bones.¹ The principles of DO have now been applied to the correction of maxillofacial deformities, offering new and exciting possibilities for treatment of deformities in the maxillofacial region. DO has shown significant promise in improving treatment for severe mandibular deformities, such as craniofacial microsomia, Treacher Collins syndrome, and other similar mandibular deformities, as well as a wide variety of midface abnormalities. There are several potential advantages to the use of DO for the correction of severe mandibular abnormalities. Most importantly, it appears that DO offers the possibility of obtaining results in some cases that simply cannot be achieved with more traditional osteotomy procedures. DO with initial encouraging results have prompted many surgeons to consider applying these surgical principles to less severe deformities, abandoning traditional

orthognathic osteotomy procedures. In a recent publication, it was suggested that the introduction of DO would bid “a farewell to major osteotomies.”²

Although DO shows promise for the treatment of severe deformities, most practitioners would likely agree that less severe abnormalities, such as mandibular deficiencies in the 3 to 7 mm range, are best treated with routine surgical correction using the BSRO. The controversy arises when considering the treatment of more severe mandibular deficiencies, such as those over 8 to 10 mm. This chapter provides the basis for the use of traditional orthognathic surgery (the BSRO) for correction of mandibular deficiency and compares the advantages and efficacy of this treatment approach with those of DO.

When new surgical techniques are introduced, the excitement of expanding the realm of surgical treatment is often hard to resist. The temptation to begin treatment using new techniques is often accentuated by advances in instrumentation or appliances. When applying a new surgical technique to clinical situations in which other techniques are available, the risks and benefits of the technique must be compared with traditional surgical procedures. In 1990, Dr. Daniel Laskin stated that “justification for using any clinical procedure must be based on proof of its efficacy, its ability to improve the net health outcome, the fact that it is at least as beneficial as any previously established alternatives and the ability to obtain the results outside of the investigational setting.”³ The net health outcome should be considered as a total value obtained by adding the advantages and benefits of the procedure and subtracting the disadvantages and risks. Although DO may have some minor advantages over the BSRO for treatment of the large mandibular

advancements, the net clinical value of the procedures, considering stability and predictability for surgical and orthodontic outcome, time in treatment, morbidity, cost efficacy, and patient acceptance, clearly weighs in favor of the sagittal osteotomy.

Historical Development of the BSRO

Surgical techniques for the correction of skeletal deformities in the mandible have evolved considerably in approach, design, and stabilization. Early surgical intervention for mandibular lengthening focused on vertical osteotomies in the ramus through extraoral approaches. Trauner and Obwegeser, in the early 1950s, introduced intraoral sagittal splitting of the mandible to correct skeletal deformities.⁴ The technique introduced intraoral splitting of the mandible in the sagittal plane through an oblique cut in the vertical portion of the ramus (Figure 27-1A). The ability to correct multiple skeletal deformities with a single osteotomy design helped to forward acceptance and application of the technique. Dal Pont modified the osteotomy by creating the anterior lateral cut of the osteotomy in a more vertical direction and placed the cut in the posterior body of the mandible.⁵ The completion of the osteotomy between cortical plates in the retromolar region lengthened the respective segments and facilitated greater bony overlap when repositioned (Figure 27-1B). Hunsuck refined the technique further by eliminating the extension of the osteotomy to the posterior border of the mandible.⁶ The inherent lack of osseous thickness in the ascending ramus posterior to the mandibular foramen was the anatomic foundation for altering the osteotomy (Figure 27-1C).

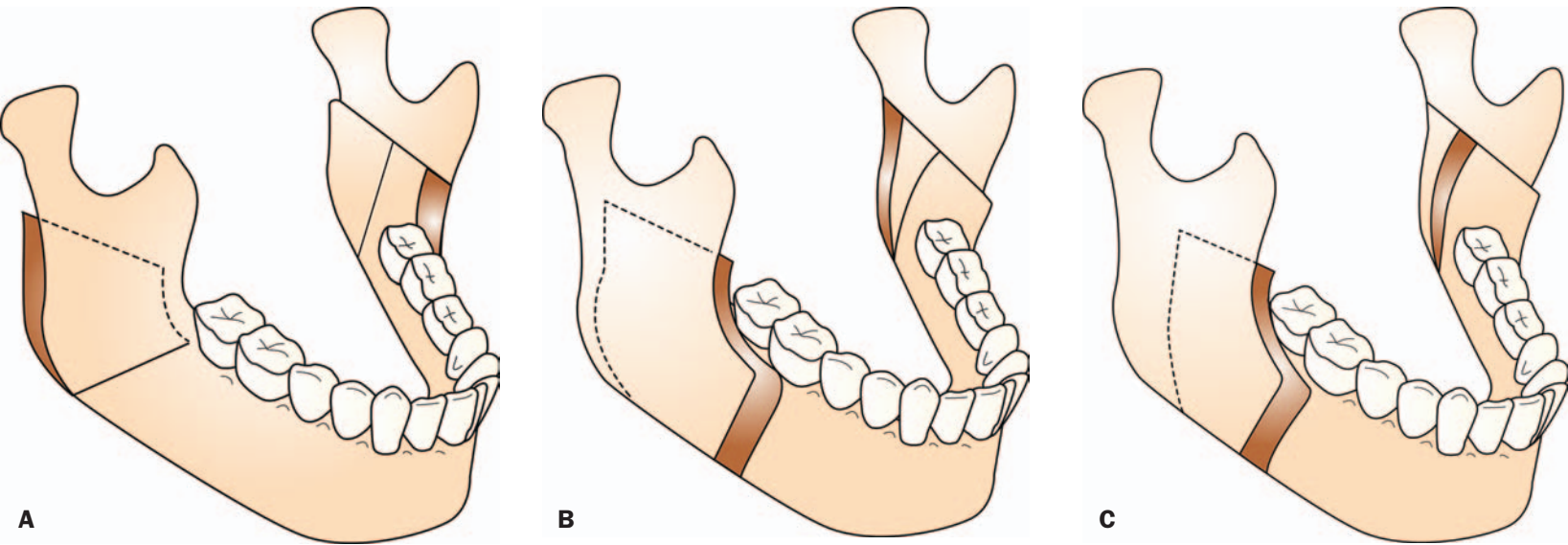


FIGURE 27-1 Modifications of the bilateral sagittal ramus osteotomy. A, Trauner and Obwegeser: splitting the mandible via oblique cuts through the vertical aspect of the ramus.⁴ B, Dal Pont: vertical lateral cut positioned more anterior in the molar region.⁵ C, Hunsuck: eliminated extension of the osteotomy to the posterior border of the mandible.⁶

Biologic Basis of Sagittal Ramus Osteotomy

The biologic principles surrounding many of the modifications of sagittal split osteotomy are based on improving bone healing through maintenance of blood supply to the mobilized segments. Initially, the release of the muscular sling was advocated to facilitate access for completion of the osteotomy. An improved understanding of the biologic basis of the BSRO has placed more emphasis on maintaining blood supply to the osteotomized segments by minimizing stripping of tissue from the bony attachment. Bell and Schendel evaluated bone healing via histologic and microangiographic studies following traditional orthognathic techniques in an animal model.⁷ Intraosseous ischemia and necrosis were significantly reduced by limiting the extent of soft tissue reflection on the bony segments. The study advanced the principles of maintaining soft tissue attachment and the corresponding vascular supply to facilitate bone healing at the osteotomy site.

Surgical Procedure

The primary advantage of the BSRO is that this is the procedure most commonly performed by oral and maxillofacial surgeons for correction of mandibular deficiency. Most residents obtain substantial experience with the sagittal osteotomy during training and often have experience managing a wide variety of mandibular abnormalities using this procedure. This broad-based experience has provided the patient population with a large number of surgeons experienced in and

capable of effectively managing mandibular deficiency using this treatment. Obviously, DO has been used for a much shorter period of time; thus, many surgeons have no experience with this technique. Although this in itself should not be a deterring factor, surgeons, orthodontists, and patients all must recognize that there is certainly a learning curve to all aspects of DO treatment, including performing the surgical procedure itself. It is also important to note that the number of more severe mandibular advancements, such as those over the 8 to 10 mm range, comprise an extremely small portion of the patient population requiring surgical correction.⁸ Even surgeons familiar with the DO techniques will have few occasions to use DO, again resulting in less familiarity and experience compared with BSRO (Table 27-1).

Surgical Technique

The surgical techniques used to perform the BSRO are often as different as the surgeons performing this operation. Although a few basic

principles apply, a number of surgical modifications and a variety of different instruments provide the surgeon with the ability to perform this operation effectively with a minimum of complications. The following is a description of our technique for the BSRO.

After routine preparation and draping for an osteotomy procedure, the area of the incision in the buccal vestibule is injected with diluted epinephrine, usually combined with a local anesthetic. The medial side of the mandible is also injected, attempting hydrostatically to begin the subperiosteal dissection in the area above the lingula. The initial incision is made well lateral (approximately 3 cm) to the external oblique ridge area. This incision is made through mucosa only (Figure 27-2). The medial aspect of the incision is then pulled medial to the external oblique ridge, and another incision is made through the periosteum (Figure 27-3). This combination of mucosal and periosteal incisions provides excellent access to expose the mandible for osteotomy cuts but also allows for adequate access for suturing during wound closure. A subperiosteal dissection is then completed to expose the lateral aspect of the anterior portion of the ramus, and a notched retractor is used to expose the anterior portion of the ramus to the area of the coronoid process. A subperiosteal dissection on the medial aspect of the mandible exposes the lingula, inferior alveolar nerve, and retrolingular depression.

We complete all cuts with a reciprocating saw. The osteotomy is begun with a horizontal cut on the medial aspect of the mandible. This cut is made above the area of the lingula and extends posteriorly through the bulge on the medial aspect

Table 27-1 Surgical Procedures, 9/1/01 to 9/1/03: Cases with Resident Participation	
Procedure	n
Mandibular osteotomies	151
Maxillary osteotomies	98
Double jaw	103
Total mandibular procedures	254
Distraction cases	8



FIGURE 27-2 Mucosal incision positioned laterally provides access to the mandible with the ability to close the wound easily.

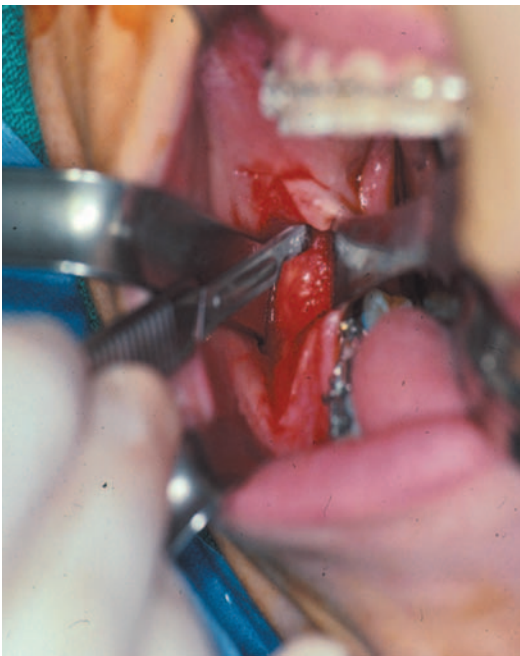


FIGURE 27-3 Periosteum sharply incised over the external oblique ridge adjacent to the superior margin of the incision aids in exposure of the ramus.

of the ramus that forms the anterior portion of the retrolingular depression. The saw blade extends through the posterior portion of the bony prominence inferiorly to define the posterior superior aspect of the osteotomy (Figure 27-4).

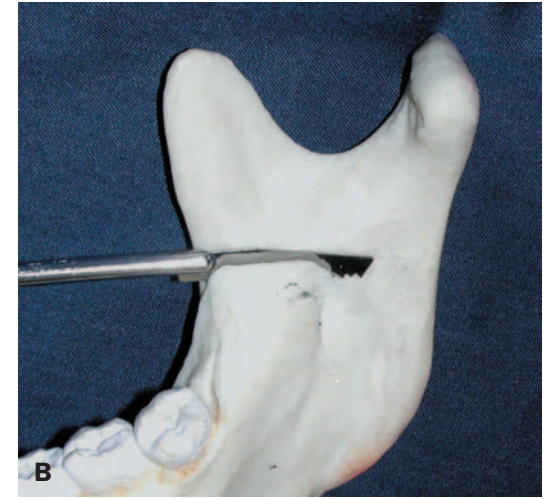
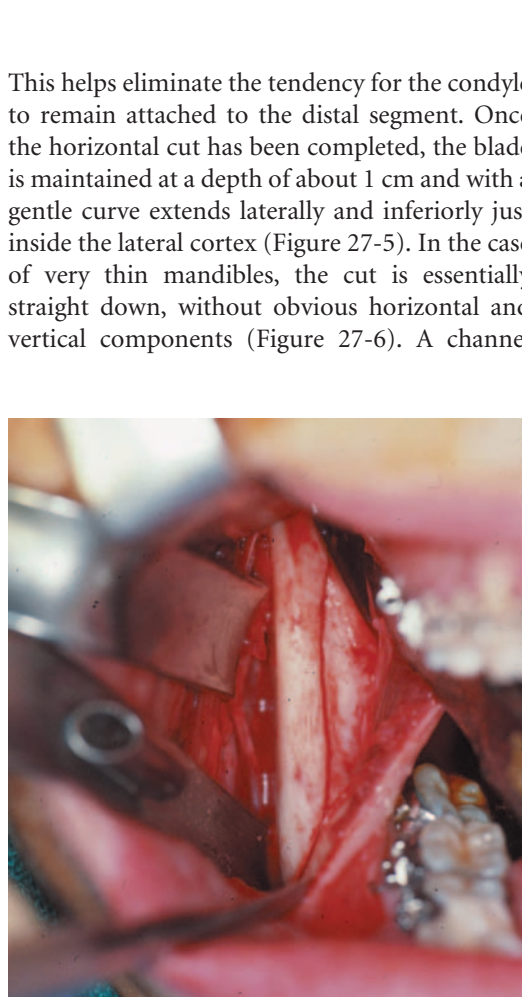
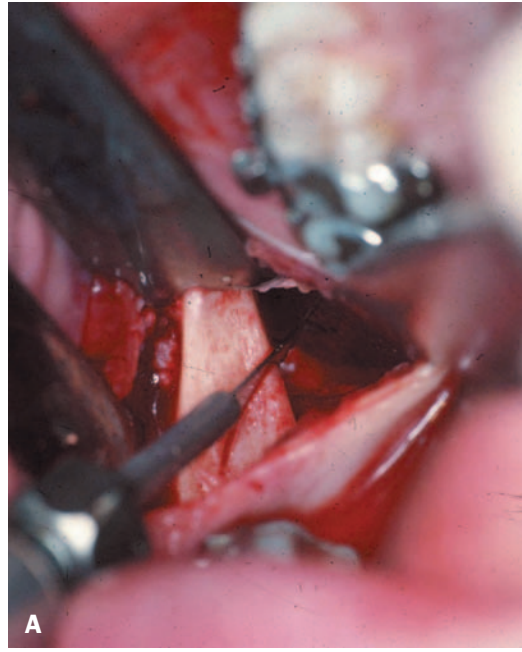


FIGURE 27-4 A, Reciprocating saw initiating the medial cut. B, Extending the saw cut to retrolingular depression superior to the lingula.

This helps eliminate the tendency for the condyle to remain attached to the distal segment. Once the horizontal cut has been completed, the blade is maintained at a depth of about 1 cm and with a gentle curve extends laterally and inferiorly just inside the lateral cortex (Figure 27-5). In the case of very thin mandibles, the cut is essentially straight down, without obvious horizontal and vertical components (Figure 27-6). A channel

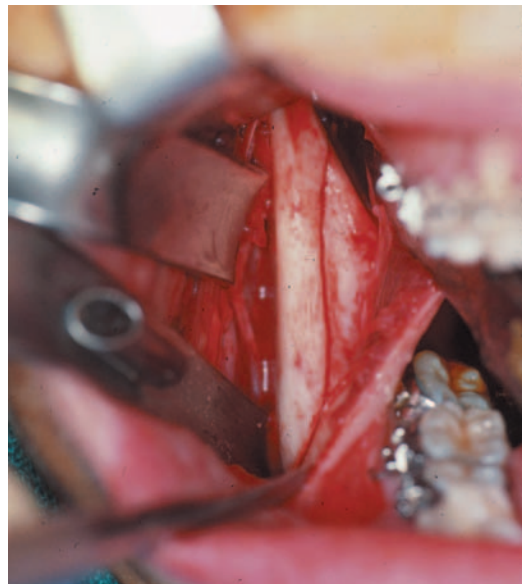


FIGURE 27-5 A gentle curve in the osteotomy along the ascending ramus and posterior body prevents stress lines during separation. The osteotomy cuts penetrate the medullary bone and parallel the lateral cortex.

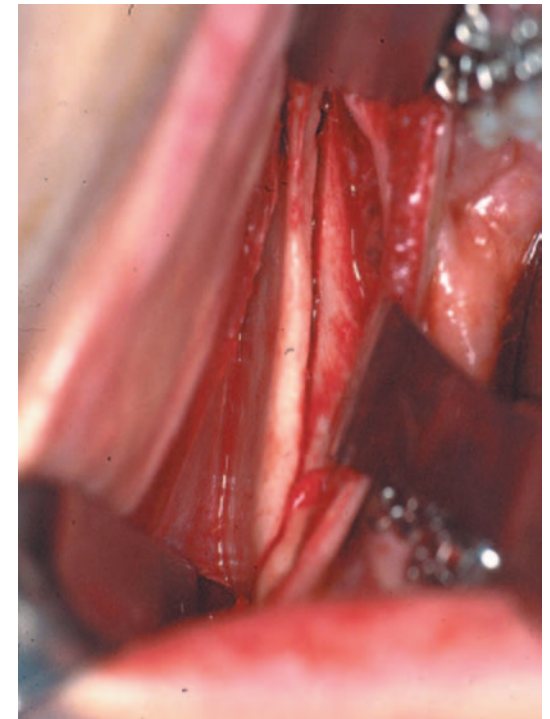


FIGURE 27-6 Straight osteotomy design employed owing to insufficient width of the ramus.

retractor is then placed laterally under the inferior border of the mandible. The reciprocating saw is used to create the lateral vertical portion of the osteotomy slightly tangential to the lateral

border of the mandible (Figure 27-7). The goal is to connect the osteotomy cuts without sharp corners, which increase localization of force and may contribute to unanticipated fractures during segment separation. A sequence of osteotomes or spreaders can then be used to separate the segments (Figure 27-8). To decrease muscular and tendinous tension, a J stripper is used to release muscle and periosteal attachments from the posterior and inferior aspects of the distal segment (Figure 27-9). After passively positioning



FIGURE 27-7 Lateral cut performed in a tangential manner to facilitate access and separation. A channel retractor aids in completing the inferior border cut.

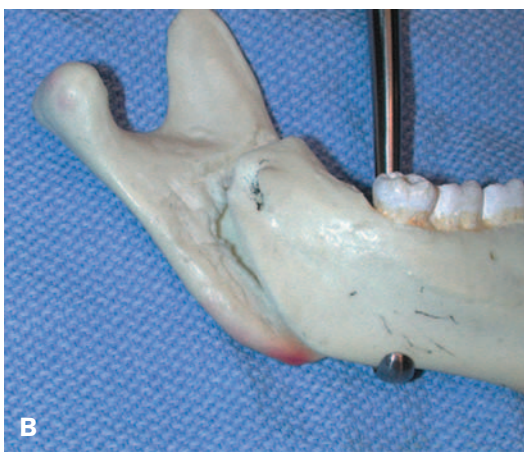
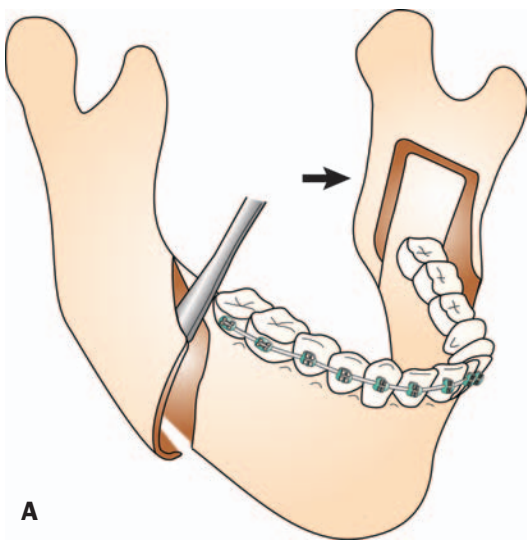


FIGURE 27-9 A, Diagram of areas in which muscle and tendon attachments are released. J stripper used to release the soft tissue attachment at the inferior border (B) and medial surface (C) of the distal segment.

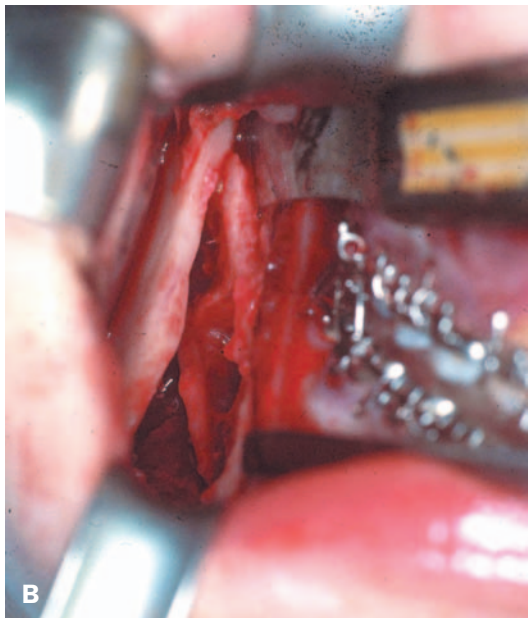


FIGURE 27-8 A, Initial separation of the osteotomy with an osteotome positioned in the vertical cut. Separation is performed with visualization of the entire osteotomy to prevent unfavorable splitting. B, Completion of the osteotomy is performed after identifying the neurovascular bundle and ensuring complete separation of the inferior border.

the distal segment into occlusion with a prefabricated splint and maxillomandibular fixation, the segments are then fixed in place with a variety of rigid fixation techniques using screws and/or plates (Figure 27-10). The fixation is usually completed through a percutaneous approach.

Patients undergoing a BSRO can easily be treated with very short periods of hospitalization. In today's environment, most patients undergoing this procedure are treated with less than 24-hour hospital stays. This may range from a 23-hour same-day admission to an in-and-out surgical center experience.

Surgeons advocating DO suggest that this procedure may be even more amenable to a short surgical center procedure with very short postoperative stays. The assumption is that DO requires less manipulation during this surgical procedure because the osteotomy is not repositioned in the same fashion as with traditional orthognathic surgery. Some surgeons advocate placement of the distraction appliance followed by creation of a simple vertical osteotomy on the posterior body or ramus area and subsequent distraction.⁹ Since

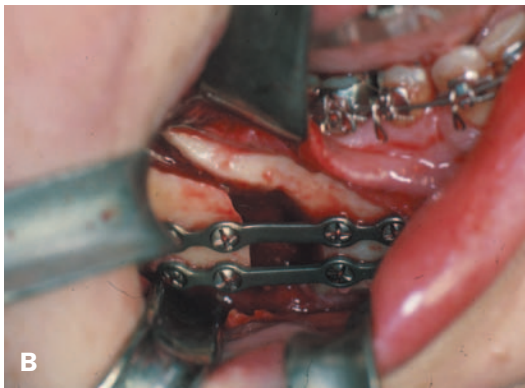


FIGURE 27-10 A, Stabilization of the advancement with lag screws positioned at the superior border via percutaneous access. Adaptation of the proximal and distal segments provides a favorable bone interface. B, Rigid fixation with bone plates across the osteotomy gap.

an aggressive separation at the osteotomy site is usually not completed with DO, it is proposed that this procedure may be performed using intravenous sedation rather than a general anesthetic. There are some circumstances in which there are only minimal differences between DO and BSRO surgery. The use of a standard sagittal ramus osteotomy design followed by use of a distraction appliance has been reported.¹⁰ In this case, it seems that the surgical procedure would require the time necessary to perform the sagittal osteotomies bilaterally in addition to the time required for adaptation and placement of the distraction appliances. A standard ramus osteotomy can easily be performed in 60 to 90 minutes. It is hard to imagine that placement of distractors

bilaterally followed by completion of osteotomies in both areas can be done in a significantly shorter time. Table 27-2 shows the difference in time required to complete a BSRO compared with DO.

One of the most obvious advantages of traditional orthognathic surgery is the ability to complete the correction in one surgical event. DO requires at least two surgical procedures: one to create the osteotomy and place the distraction devices and a second procedure for removal of the distraction device. On some occasions, further soft tissue revision is required. Patients are therefore subjected to the risks associated with at least two surgical procedures and associated anesthetics.

Table 27-2 Time to Complete Surgical Procedure (Effects of Morbidity and Cost of Surgery)	
Procedure	Time (min)
BSRO with RIF (no third molars)	
With resident	80
With partner	47
Distraction	
With resident	115
With partner	92
BSRO = bilateral sagittal ramus osteotomy; RIF = rigid internal fixation. At \$17 to \$24 per minute, this becomes expensive.	

Morbidity

The risks, potential complications, and expected morbidity associated with sagittal ramus osteotomies for correction of mandibular deficiency are well known. DO, on the other hand, has not been subjected to the same long-term scrutiny. Common sense would suggest that many risks associated with the initial surgical procedure would be similar for both traditional treatment and DO, although this has not been documented.

Postoperative pain seems to be quite different for DO patients compared with those undergoing BSRO. In the immediate postoperative period following BSRO, patients often receive two to three doses of intramuscular or intravenous analgesics. This is followed by 1 to 3 days of mild narcotics or over-the-counter analgesic preparations. Most patients do not require significant analgesic medication of any type after this point. Distraction patients often maintain some level of discomfort during the period of distraction, often requiring narcotic pain medication for longer periods of time. Table 27-3 shows the difference in the level of analgesic consumption between patients undergoing BSRO or DO.

Table 27-3 Morbidity (Postoperative Pain)	
	Number of Doses
Conventional surgery (n = 200)	
Postoperative IV medications (morphine or meperidine)	3
Oral medications (usually hydrocodone)	6
Distraction osteogenesis (n = 8)	
Postoperative IV medications (morphine or meperidine)	4
Oral medications (usually hydrocodone)	26
IV = intravenous.	

The advantages of a single surgical experience with traditional osteotomy treatment should be apparent. DO obviously requires at least two surgical treatments. In some cases, patients have significant mucosal scarring in the area surrounding the appliance or in the area of the appliance activation device. This occasionally requires further revision surgery. In a few cases, there appears to be a loss of attached gingival tissue lateral to the teeth near the intraoral distraction appliance. The long-term, periodontal implications of this are not clear.

Predictability

Traditional sagittal ramus osteotomy correction of mandibular deficiency allows the surgeon to predictably move the mandible to the desired position in multiple planes of space. It is extremely rare that correction of mandibular deficiency involves a pure and simple anterior-posterior movement. More frequently, surgical correction becomes multidirectional. Class II deep-bite patients require anterior-posterior correction and clockwise movement in the sagittal plane to achieve the appropriate incisor overjet while maintaining posterior tooth contact. Many patients have varying degrees of midline or archform asymmetry requiring rotation of the dentoalveolar segment as part of the correction. Although some contouring or other manipulation of the proximal and distal segment interface must be completed, these variations in surgical movement can easily be accommodated with the sagittal ramus osteotomy. With the use of rigid fixation, the occlusal and skeletal position can be easily verified after release of fixation and manipulation of the mandible in the operating room with the opportunity for immediate adjustment if necessary.

Corrections of abnormalities that require multidirectional movement can be extremely difficult with DO. In fact, maintaining a simple straightforward movement of the mandible is often complicated by undesirable rotational movements of the mandible in all three planes of space. It is not uncommon to see midlines drift to one side, creating a mandibular asymmetry. The

tendency for development of an open bite also appears to be common during the distraction period. These undesirable movements are the result of difficulty in controlling vectors related to the positioning of the distraction appliances. In the case of straightforward movement, if the appliance is not exactly parallel to the occlusal plane, movements in the vertical plane of space will occur. Variations in the shape of the mandible or minor asymmetric placement of the distraction appliances may result in midline asymmetries or asymmetric posterior open bites. These problems decrease the predictability of the immediate surgical outcome, complicate postoperative orthodontic treatment, and may compromise the desired occlusal and skeletal result. Table 27-4 summarizes the potential advantage of the BSRO in terms of predictability.

Treatment Time for Patients, Surgeons, and Orthodontists

Surgical Follow-Up

Following traditional orthognathic surgery, a typical postoperative follow-up routine may involve appointments at 1 week, 3 weeks, and 6 weeks. Patients then return to orthodontists for postoperative orthodontic treatment and may be seen by the surgeon at 4 to 6 months after returning to the orthodontists or at the time of debanding. Orthodontists may see the patient on

Table 27-4 Predictability (Immediately Postoperatively)
Conventional surgery
Ability to produce movement in three dimensions
With RIF can check position/occlusion in OR
Surgical result usually more precise
Distraction osteogenesis
Multidimensional moves more difficult to plan/predict
Unable to check occlusion in the OR; evolves over weeks
Surgical result usually less precise
OR = operating room; RIF = rigid internal fixation.

a 3- to 4-week basis until debanding and enter the patient into their routine retention follow-up program. Patients are usually followed by the surgeon at yearly intervals after debanding, but this usually does not result in further treatment. This routine is easily manageable for patients who work or are in school. This is also very manageable for surgeons and orthodontists.

The time devoted to treatment by patients, surgeons, and orthodontists is drastically different when DO is the technique used for mandibular advancement. Patients should be followed very closely during the distraction phase after discharge from the initial surgical intervention. Some surgeons suggest that patients should be seen daily while in active distraction. When malocclusions result from the vector problems described above, orthodontists may also need to become actively involved in follow-up and patient management. Patients are then seen at weekly or biweekly intervals during the consolidation phase, often by both the orthodontist and the surgeon. A second surgical procedure is then required for removal of the distraction appliance with more postsurgical appointments. Owing to the difficulty in achieving the same precision and occlusal result, orthodontic treatment will most likely require more postoperative visits to achieve the desired results. This sequence of events results in more appointments when compared with traditional surgical correction. Table 27-5 compares the postoperative appointments with the surgeon.

Orthodontic Follow-Up after Surgery

Orthodontic management of surgical cases following traditional osteotomies has become relatively routine and predictable. In most cases, orthodontic detailing can be completed in 3 to

Table 27-5 Follow-Up: Surgical Postoperative Visits
Conventional surgery
1 wk
3 wk: splint removed
6–8 wk
4–6 mo: debanding
Total appointments: 4
Distraction osteogenesis
1 wk (5 d)
Every 2 or 3 d during distraction
2 wk after distraction
6 wk after distraction
Distractor removal
1 wk after removal
4 wk after removal
Every 8–12 wk until debanding (8 mo—3 appointments)
Total appointments: 14

6 months after surgery. This may involve leveling of occlusal planes, as in the case of Class II deep-bite malocclusions set in a tripod relationship at the time of surgery. In other cases, the final orthodontic phase may involve only minor adjustments to achieve the best possible posterior interdigitation, remove minor malrotations, increase root parallelism, and refine overbite and overjet. The presence of minor posterior or anterior open bites can usually be managed with appropriate orthodontic mechanics.

In DO cases, it is apparent that it is much more difficult to achieve a refined predictable occlusal relationship immediately after surgical correction. As described above, many undesirable asymmetric or vertical rotations may occur. This often results in much more intensive orthodontic treatment in the postsurgical phase. Table 27-6 outlines the typical number of postsurgical orthodontic appointments for both types of treatment. This may require an inordinate amount of absence from school or work for patients and parents. For surgeons and orthodontists, this detracts from the time required for treatment of other patients.

In some DO cases, more aggressive types of postsurgical management may be required, including the use of extraoral devices such as headgear and chin cups. The use of aggressive elastic traction in a variety of unusual vectors has also been described.¹¹ It is hard to imagine that this could result in a more precise final orthodontic outcome than traditional orthognathic surgery. Aggressive intraoral elastic traction may be able to “mold” the regenerate and produce some skeletal change. It would also be expected that some of the resulting change in occlusal position would be a result of dental change rather than skeletal repositioning. This has been shown to occur in rigid internal fixation patients subjected to only light elastic traction in the postoperative period.¹² With stronger forces placed on the dentition, these changes could be expected to be much greater and may have some effect on predictability and long-term stability.

All of this treatment certainly has the potential to diminish the patient’s enthusiasm during the course of management. There is substantial

psychological evidence to show that patients maintain enthusiasm for treatment for a limited period of time after surgery. Kiyak and Bell demonstrated that patient satisfaction with surgical and orthodontic treatment seems to improve slightly over approximately a 4-month period after surgery.¹³ However, following this initial postsurgical phase, they demonstrate a steady decline over the subsequent 5 months. For most patients, the surgical event seems to represent an emotional climax. Following this event, it often becomes hard to maintain motivation and enthusiasm for continued treatment. In traditional orthodontic and surgical treatment, the best approach usually involves accomplishing as much orthodontic preparation as possible prior to surgery such that orthodontic treatment can then be completed within 3 to 6 months following surgery. When more orthodontic treatment is required after surgery and the length of postoperative treatment is extended, this may result in decreased patient interest and compliance. The use of elastics in multiple vectors, the possible use of extraoral appliances, and an increased number of appointments obviously require significant patient compliance. In the event that a patient fails to participate fully in any aspect of appliance wear or follow-up treatment, this may further compromise the end skeletal and occlusal result.

Stability

A significant body of literature documents the postsurgical stability of mandibular advancement using the BSRO.^{14–27} Most studies of stability following mandibular advancement demonstrate some degree of postsurgical change. In studies of smaller mandibular advancements (under 8 mm), this relapse appears to be minimal. There is evidence that larger advancements in excess of 8 mm result in greater postsurgical change.^{25–27} In a report by McDonald, a group of patients undergoing mandibular advancement with a mean of 12.1 mm showed an average relapse of 3.5 mm.²⁵ In these larger advancements, the relapse appears to be multifactorial and related in some degree to the amount of advancement. One factor assumed

to play a part in this relapse is the acute stretching of the soft tissue components, including muscles and tendons. It appears that these soft tissue components have the potential to adapt to positional changes within a short period of time.²⁸ During this period of adaptation, additional surgical modalities, such as suprahyoid myotomies and short-term suspension wiring, can be implemented to reduce the forces contributing to relapse.^{27,29} VanSickels demonstrated that the use of rigid internal fixation combined with short-term suspension wiring resulted in minimal relapse in a group of patients undergoing advancements over 12 mm.²⁷

Increased stability has been cited as one of the main advantages of DO for lengthening the deficient mandible. This potential increase in stability appears to result from gradual distraction of the mandibular skeletal component and the entire associated soft tissue complex, including the periosteum, muscles of mastication, subcutaneous tissue, and skin. Because of the slow expansion of the soft tissue envelope, gradual adaptation occurs over the distraction and consolidation period, with reports of less postsurgical change.³⁰ However, it is impossible to compare DO with traditional orthognathic surgical treatment of mandibular deficiencies owing to the lack of published studies evaluating the stability after DO in large numbers of patients. Although many anecdotal case reports demonstrate promising results, there is simply not sufficient evidence provided through long-term controlled studies to demonstrate increased efficacy of DO stability when measured by the same traditional yardsticks used to evaluate mandibular advancement with the BSRO.

Implications for the Temporomandibular Joint

The effect of the BSRO on the temporomandibular joint has been extensively evaluated. For the most part, asymptomatic patients are not adversely affected by sagittal ramus osteotomy. Most patients who have preexisting joint symptoms actually experience improvement as the result of sagittal ramus osteotomy.^{31–33} There is some evidence that a very small percentage of patients who were previously asymptomatic will develop symptoms of pain or dysfunction following surgery. It is also possible that patients who have preexisting symptoms may have some worsening of their problem, although these percentages are extremely small. The effect of DO on the temporomandibular joint remains in question. Since DO results in gradual stretching of bone and adjacent soft tissue, the hypothesis is that this may result in decreased abnormal loading on the joint. This remains to be seen as a large number of patients

Table 27-6 Orthodontic Treatment following Surgery

Conventional surgery
Appointment at time of splint removal or 4–6 wk postoperatively
Appointment every 3–4 wk for duration of treatment
Usually 4–6 mo
Total appointments: 6
Distraction osteogenesis
Appointment shortly after distractor removal (often seen during distraction)
Appointment every 2–3 wk for duration of treatment
Usually > 8 mo
Total appointments: 12

will need to be followed for a significant amount of time to evaluate this issue.

Neurosensory Issues

One of the major disadvantages of the sagittal ramus osteotomy is the resulting neurosensory deficit, which may be temporary or, in some cases, permanent.^{34,35} This can result from direct trauma to the nerve, including laceration or complete transection. Neurosensory abnormalities may also occur when no apparent injury occurred at the time of surgery. Simple manipulation of the nerve during surgery and stretching in the case of advancement may be the sole cause of the persistent neurosensory abnormalities. DO may decrease the incidence of neurosensory deficit by decreasing the amount of acute manipulation and stretching that occurs at the time of surgery. Gradually stretching the soft tissue structures, including the nerves, may result in a better neurosensory outcome. As with many aspects of DO, there is not enough evidence in the literature to support improved neurosensory outcome.

Cost-Effectiveness

In today’s health care environment, there is increasing pressure to reduce the cost of medical care. Treatment outcome is evaluated not only on the final outcome but also on the cost required to cure a disease or improve an abnormality. The cost of traditional orthognathic surgery, as with most aspects of medical care, has increased over the past two decades. There are some areas in which cost has been reduced through efficient management of hospital resources, shorter hospital stays, and quicker patient recovery.³⁶ However, operating room charges have increased dramatically. Lombardo and colleagues documented that the operating room charges associated with orthognathic surgery went from 50% of the total hospital bill in 1985 to 80% in 1992.³⁶ Much of this cost can be attributed to rigid fixation. DO significantly increases the cost of treatment over traditional orthognathic surgery. Intraoral distraction appliances can range from \$800 to \$2,000 per side or an additional \$1,600 to \$4,000 per case for the hardware. The need for two surgical procedures also dramatically increases costs, with the resulting need for a second anesthetic, a

second operating room charge, and an additional surgeon’s fee. (Tables 27-7 and 27-8 show the difference in cost, not including the surgeon’s fee, of BSRO versus DO.)

In addition to the actual treatment fees and facility charges, the economics related to patient and family time expended and the increased time commitment from both surgeons and orthodontists must be viewed as a disadvantage of DO. Even if DO were to be deemed the technique that produced the “ideal outcome,” this would be unacceptable if the cost and time commitment were more than twice as much as those for traditional surgical treatment, which results in a

Table 27-7 Cost-Effectiveness: Outpatient Surgery	
	Cost
Conventional surgery	
Outpatient OR	500
Hardware	192
Anesthesia	800
Total	1,492
Distraction osteogenesis	
Hospital OR	500
Hardware	4,744
Anesthesia	800
Second surgery (IV sedation only)	300
Total	6,344
IV = intravenous; OR = operating room. Does not include surgeon’s fee.	

Table 27-8 Cost-Effectiveness: Inpatient Surgery	
	Cost
Conventional surgery	
Hospital	3,750
Hardware	500
Anesthesia	800
Total	4,950
Distraction osteogenesis	
Hospital	4,250
Hardware	6,150
Anesthesia	800
Hospital	1,800
Anesthesia	500
Total	13,000
Does not include surgeon’s fee.	

very satisfactory outcome but with a significant reduction in cost.

Patient Satisfaction

Critical review and reassessment of treatment options by surgeons and orthodontists are a vital part of continued progress in the treatment of patients with dentofacial deformities. Despite the scientific data and opinions of surgeons and orthodontists, much of the acceptance related to specific procedures will be based entirely on patient satisfaction. How patients view treatment will ultimately be a result of their assessment of the “net value” of the treatment method they have chosen. In an ideal world, the end clinical result would be the only factor receiving consideration in deciding which treatment is the most appropriate. In the real world, the final assessment will be based on how patients view the end result combined with what sacrifices they are required to make to achieve that result. At this point, DO offers some promise for the possibility of achieving results in the treatment of severe abnormalities not previously obtainable. However, the significant disadvantages of multiple surgical procedures, increased time commitment to receive treatment, and substantial increase in cost may far outweigh the minor improvement in treatment result that may, in the end, be appreciated only by academic statistical analysis, with little relevance to patient satisfaction. Therefore, at the present time, traditional orthognathic surgical management with sagittal ramus osteotomy for mandibular advancement remains the treatment of choice for mandibular deficiency.

Case Comparison

The following presentations show two patients with similar clinical situations. Both patients have severe mandibular deficiency with approximately 13 to 14 mm of overjet and additional chin deficiency. One patient underwent mandibular advancement with traditional BSRO (Figures 27-11 through 27-20), and the second patient’s mandible was advanced with DO (Figures 27-21 through 27-36). Both patients had undergone genioplasties at the time of the osteotomies. Table 27-9 compares several aspects of the treatment for each of these patients.



FIGURE 27-11 Case 1: correction of mandibular deficiency with orthognathic surgery. Presurgical clinical photographs. A, Frontal; B, profile. Mandibular hypoplasia and marked chin deficiency are demonstrated in profile.



FIGURE 27-12 Intraoral photographs, case 1. Orthodontic decompensation via mandibular second premolar extractions was accomplished to aid in maximizing the skeletal correction. A Class II relationship with a 13 mm overjet and deep bite exists.



FIGURE 27-13 Presurgical cephalometric radiograph, case 1, showing mandibular retrognathia and microgenia.

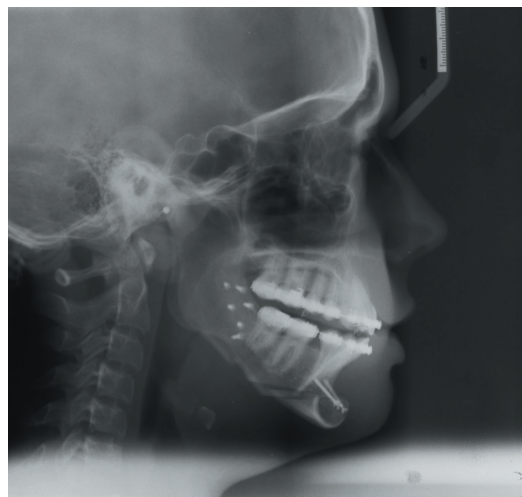


FIGURE 27-14 Presurgical cephalometric radiograph, case 1, showing mandibular advancement and genioplasty stabilized with rigid fixation.



FIGURE 27-15 Superimposition of pre- and postsurgical cephalometric tracings, case 1.



FIGURE 27-16 Intraoral photographs following surgical advancement, case 1. The correction of the Class II deep-bite relationship was accomplished through tripoding the occlusion, improving the deficient lower facial third. Orthodontic detailing will allow for the leveling of the occlusal plane.



FIGURE 27-17 Clinical photographs at the completion of treatment, case 1. A, Frontal; B, profile. Correction of the deficient mandible and chin has improved the balance between the facial thirds and provides an aesthetic profile.



FIGURE 27-18 Final intraoral photographs, case 1. The occlusion following orthodontic debanding illustrates the proper overjet and overbite. A stable final occlusion can be expected secondary to the solid posterior interdigitation. A pseudo-Class III molar relationship exists secondary to the mandibular extractions for orthodontic decompensation.



FIGURE 27-19 Two-year postoperative cephalometric radiograph, case 1.

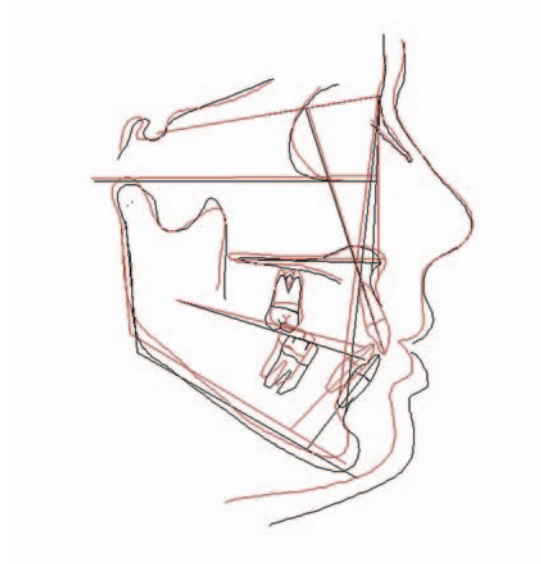


FIGURE 27-20 Superimposition of immediate postoperative and 2-year postoperative cephalometric tracings, case 1. Evaluation of the tracings indicates minor skeletal relapse from original postsurgical advancement, with a slight Class II tendency. Softening of the chin is apparent in the tracing of the profile but is subjectively imperceptible.

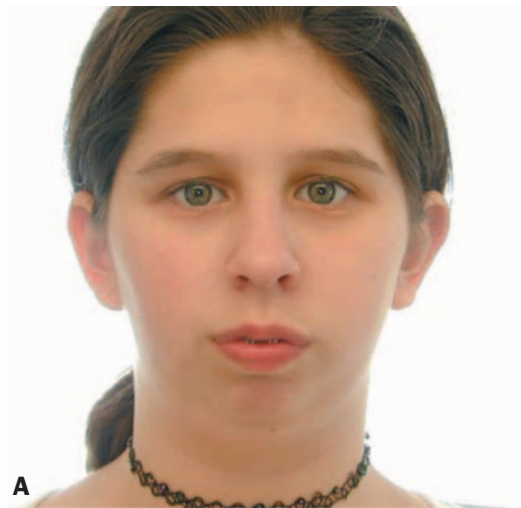


FIGURE 27-21 Case 2: correction of mandibular deficiency with distraction osteogenesis. Presurgical clinical photographs. A, Frontal; B, profile. Initial examination reveals mandibular hypoplasia and microgenia.



FIGURE 27-22 Intraoral photographs, case 2. Presurgical orthodontic preparation has provided good arch form and occlusal leveling. The dental midlines are aligned with an overjet of 14 mm and an associated Class II dental relationship.



FIGURE 27-23 Presurgical cephalometric radiograph, case 2, demonstrates mandibular retrognathia and microgenia.



FIGURE 27-24 Cephalometric radiograph, case 2, demonstrating distraction progressing. Mandibular advancement is being accomplished with intraoral distraction osteogenesis. The distraction appliances can be seen paralleling the occlusal surface of the mandibular dentition. Advancement genioplasty stabilized with lag screws improves the soft tissue profile.

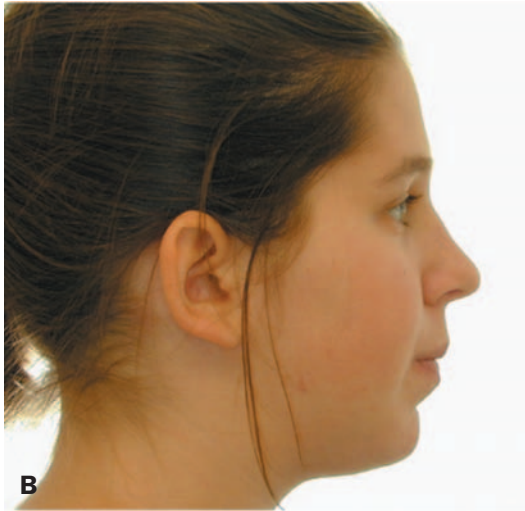


FIGURE 27-25 Clinical photographs at the completion of distraction, case 2. A, Frontal; B, profile, showing improvement in the profile.

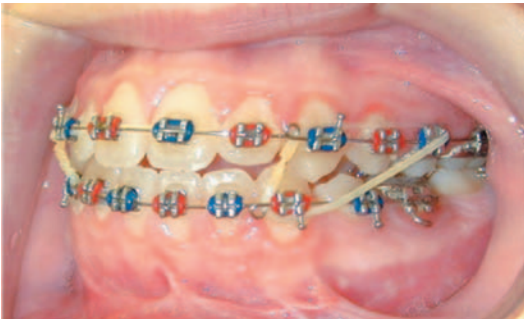


FIGURE 27-26 Intraoral photographs at the completion of distraction, case 2. Mandibular advancement through distraction with midline discrepancy and end-to-end incisor position illustrates the imprecise nature of the skeletal movement. Heavy elastic traction with multiple vectors is designed to shape the regenerate in an effort to improve the dental relationship. However, this will also result in dental and skeletal movement.



FIGURE 27-27 Cephalometric radiograph at the completion of distraction, case 2. Correction of mandibular retrognathia with distraction osteogenesis and genioplasty.



FIGURE 27-28 Superimposition of pre- and postsurgical cephalometric tracings, case 2. The tracings depict the surgical change in the mandible and occlusal relationship using distraction osteogenesis.



FIGURE 27-29 Clinical photographs after removal of the distraction appliances, case 2. A, Frontal; B, profile. Improved profile and balance between facial thirds following correction with distraction osteogenesis.



FIGURE 27-30 Intraoral photographs after removal of the distraction appliances, case 2. Orthodontic detailing continues to be focused on correcting the end-to-end incisor relationship and asymmetry.



FIGURE 27-31 Cephalometric radiograph following removal of the distraction appliances, case 2.

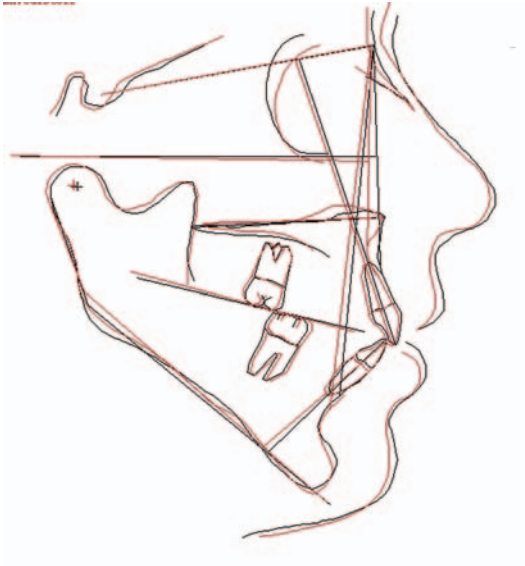


FIGURE 27-32 Superimposition of cephalometric tracings from the completion of distraction to 3 months postdistraction when distractors were removed, case 2.



FIGURE 27-33 Clinical photographs at the completion of treatment, case 2. Correction of mandibular hypoplasia with distraction osteogenesis has provided facial harmony and improvement of cosmetic concerns.



FIGURE 27-34 Final intraoral photographs, case 2. The imprecise nature of the surgical movements with distraction resulted in minor occlusal discrepancies, including the end-to-end incisor relationship and asymmetry.



FIGURE 27-35 Cephalometric radiograph 2 years postoperatively, case 2.

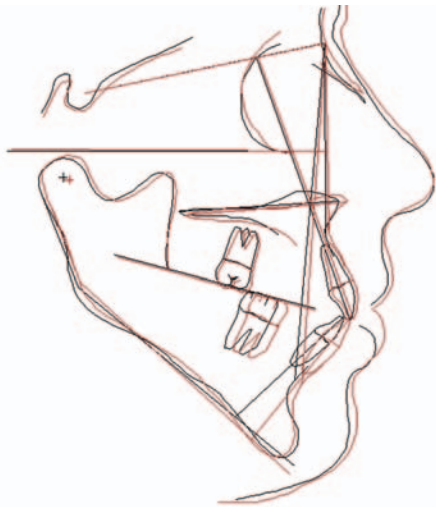


FIGURE 27-36 Superimposition of cephalometric tracings contrasting the position obtained postdistraction and at the 2-year recall illustrates a Class III tendency of the dentition accentuating the end-to-end positioning of the incisors, case 2. The overall skeletal and soft tissue change is minimal.

Table 27-9 Comparison of Treatment (Bilateral Sagittal Ramus Osteotomy vs Distraction Osteogenesis)
Conventional surgery
One surgery
Postoperative medications: 2 IV morphine doses, 5 PO hydrocodone doses
Minimal NSD
No TMJ pain or dysfunction
Postoperative occlusion very good; minor Class II tendency
Postoperative appointments: 4, surgeon; 6, orthodontist
Stability of final occlusion: 22% relapse
Total cost \$11,800
Patient satisfaction high; would recommend to friends
Distraction osteogenesis
Two surgeries
Postoperative medications, first surgery: 4 IV morphine doses, 22 PO hydrocodone doses
Postoperative medications, second surgery: 4 PO hydrocodone doses
Minimal NSD
No TMJ pain or dysfunction
Postoperative occlusion: slight asymmetry/anterior open bite
Postoperative appointments: 14, surgeon; 12, orthodontist
Stability of final occlusion: slightly more forward
Total cost \$17,800
Patient satisfaction good; happy with result but would not recommend to friends
IV = intravenous; NSD = neurosensory disturbance; PO = oral; TMJ = temporomandibular joint.

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Mandibular Lengthening Using Local Anesthesia Only as an Office-Based Procedure

Maurice Y. Mommaerts

I use the MD-DOS (Surgitec NV, Bruges, Belgium) distractor mainly to lengthen “orthognathic” hypoplastic mandibles using local anesthesia only.¹⁻³ The concept is based on a strictly intraoral approach, on a minimum of submerged foreign material, and on the avoidance of a lateral force vector in the condylar area. The procedure lasts 90 minutes and is done in the office without intravenous sedation.

The patients are properly selected, with a stable emotional status and the main desire to correct an occlusal and profile problem without hospital admittance.

A number of technical refinements have been implemented in the 8 years I have been using the MD-DOS distractor,⁴ and a perfect outcome (no open bite, correct midline) with very little morbidity is now the rule.^{5,6}

Prerequisites

Moderate linguoversion of the lower anterior teeth or labioversion of the upper anterior teeth is allowed (not reverse). Other dental compensations in the anterior region should be treated orthodontically before surgery. There should be no premature contacts on protrusion.

The third molars are removed during surgery if they are impacted. Heavy Kobayashi hooks are installed; otherwise, surgical arch bars are applied.

Tubes with a hook without offset and lingual cleats on the bands of the upper and lower first molars are preferred. Occasionally, the bands from the second molars must be removed.

Radiology

Lateral cephalometric analysis provides information on the length of the posterior fixation unit (PFU) and the length of the spacer. The length of the spacer is chosen according to the thickness

of the mucosa in the retromolar area, the position of the osteotomy line (in line with the vertical joint of the distractor), and the depth the screw may enter the bone. An orthopantomogram (panorex view) is necessary to judge the thickness of the lower border and its relationship to the mandibular canal.

Recommended Equipment

A straight handpiece, surgical motor (high torque—low speed), and instruments for the sagittal split procedure and third molar removal are recommended and the MD-DOS set.

Step-by-Step Procedure

1. When the procedure is done using local anesthesia, a mandibular and buccal nerve block is given. The incision in the buccal sulcus starts at the level of the lower occlusal plane and extends to the first molar (Figure 28-1). The lingual and buccal soft tissues are not degloved, however. Care should be taken to make the incision well away from

the buccal gingival margin when an erupted third molar is to be removed during the distraction procedure. A third molar should be removed first.

2. The pilot drill is placed lateral to the surface of the lower molar teeth (Figure 28-2A). Its point is placed lateral to the center of the ascending ramus. A marking with a round number 27 bur facilitates controlled drilling (Figure 28-2B). It is important to ensure that the distractor will interfere as little as possible with the upper dentition on laterotrusion. The pilot drill enters the ascending ramus for 8 mm maximally.

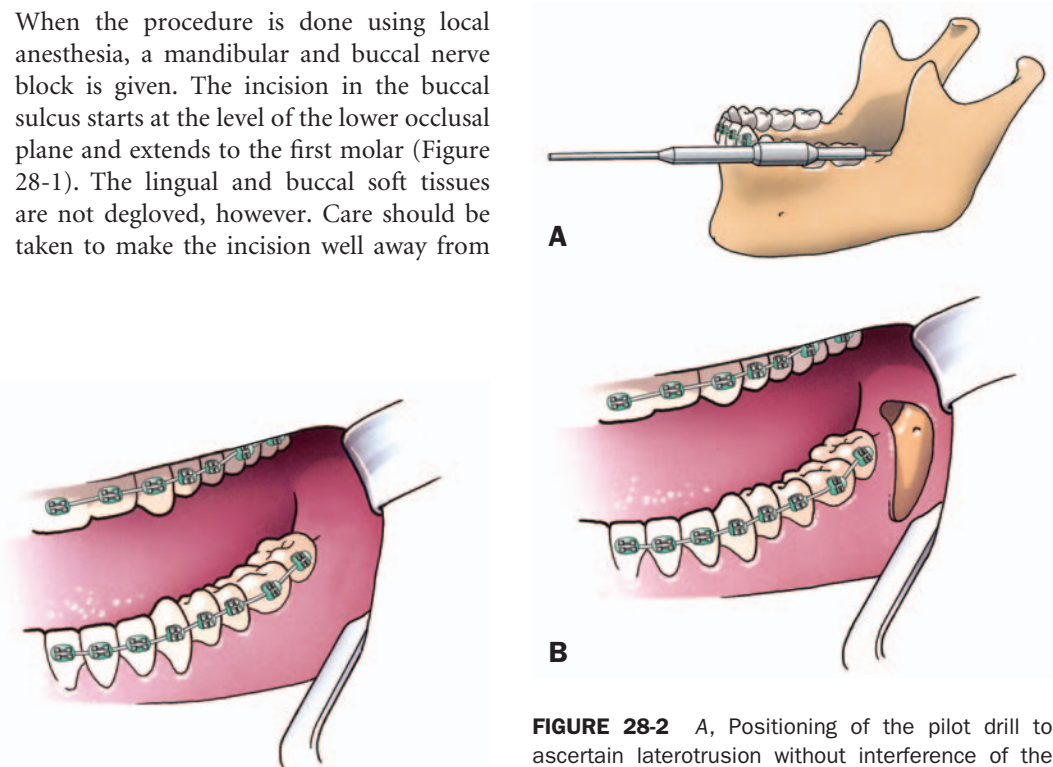


FIGURE 28-1 Buccal sulcus incision.

FIGURE 28-2 A, Positioning of the pilot drill to ascertain laterotrusion without interference of the distractor with the upper dentition. B, Marking with a round bur.

- 3. The pilot drill enters the ascending ramus for 8 mm maximally (Figure 28-3). The spacer drill will cut the bone shoulder for the spacer (Figure 28-4). It is not necessary that a 360° shoulder is created. A 180° shoulder in cortical bone is sufficient. The upper part of the cortex is left untouched to provide strong anchorage for the fixation screw.
- 4. The two-stage flat drill (Figure 28-5) and the depth drill (Figure 28-6) are used to prepare the final diameter of the bony cavity. The depth drill is used only when cortical bone is present in the depth.
- 5. The tap is used to cut the screw profile (Figure 28-7). The ratchet is rarely necessary.
- 6. The vertical hinge of the PFU is tested. Digital pressure should allow for some rotation. The PFU is applied with the PFU screwdriver (Figure 28-8). The tightness of the fit, the stability of the posterior fixation, and the future position of the corticotomy or osteotomy line are checked. The PFU is then removed.
- 7. Extra anesthetic infiltration is given intraorally at the lower border. The corticotomies are performed with a round number 27 bur. The buccal corticotomy is situated posterior to the last molar. If the third molar was impacted and removed, the corticotomy starts in the anterior part of the alveolus. The lower borders should be completely transected. The lingual corticotomy extends down depending on the position of the mandibular canal. Both corticotomies are joined, accomplishing an osteotomy at the upper border (Figure 28-9).

- 8. The green-stick fracture is done before the placement of the PFU, with a 1 cm wide sharp osteotome and a long “St. John’s mobiliser” (Figure 28-10A). The PFU is installed as described in step 6, together with the spacer. It is important that the hinge is placed perpendicular to the occlusal plane (Figure 28-10B). Gravity, suprahyoid muscle pull, and masticatory forces could otherwise create bite-opening forces. The hinge should be vertical when the screw is tight. If not, the PFU is removed and installed again.
- 9. The distraction unit is applied with the distraction unit screwdriver (Figure 28-11). It is placed in a comfortable position in relation to the cheek and the brackets.
- 10. An appropriate anterior fixation unit (A or B) is chosen and bent to accommodate both the mandibular surface and the distraction screws. The protection screw is adjusted (Figure 28-12), and the bone screws (L5 and 7 mm, diameter 2.3 mm) are fixing the plate to the cortex (Figure 28-13).

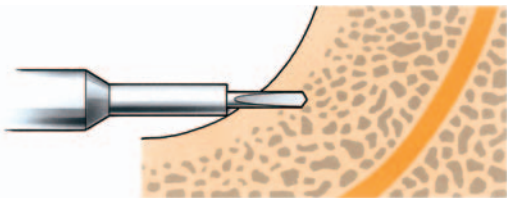


FIGURE 28-3 All drilling at a maximum of 250 rpm.

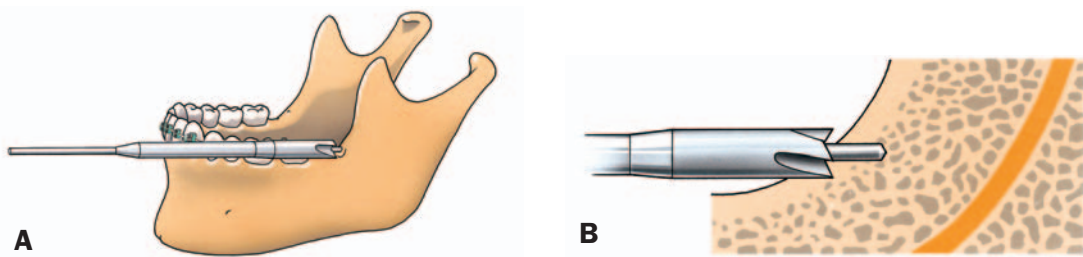


FIGURE 28-4 A and B, The spacer drill cuts a shoulder. Drilling at a maximum of 250 rpm.

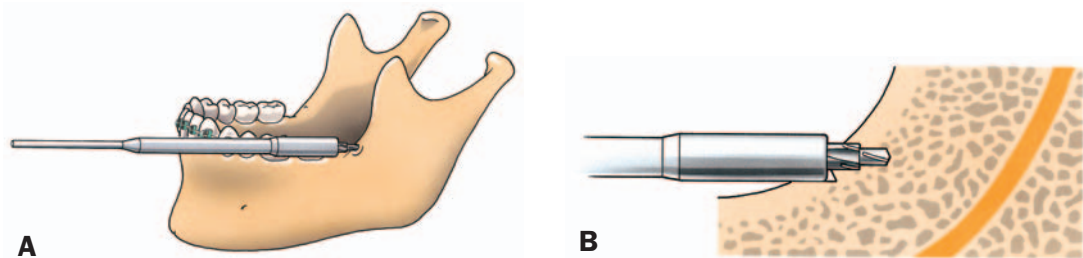


FIGURE 28-5 A and B, The two-stage flat drill. Drilling at a maximum of 250 rpm.

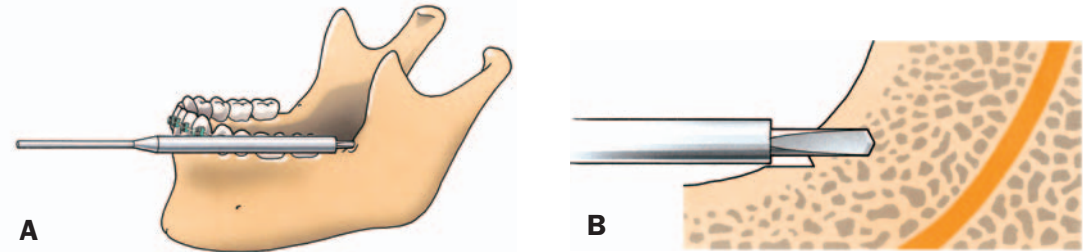


FIGURE 28-6 A and B, The depth drill. Drilling at a maximum of 250 rpm.

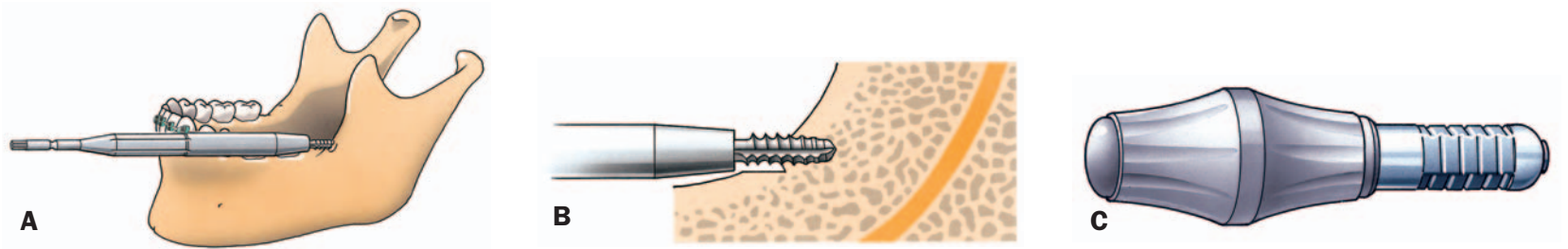


FIGURE 28-7 A to C, The tap is used with the screwdriver handle, not with the handpiece.

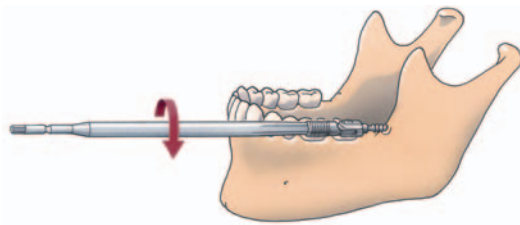


FIGURE 28-8 Testing the fixation of the posterior fixation unit.

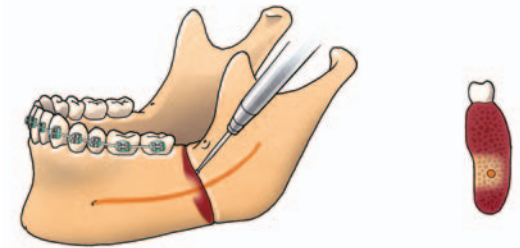


FIGURE 28-9 The buccal corticotomy is extended lingually at the upper and lower mandibular borders.

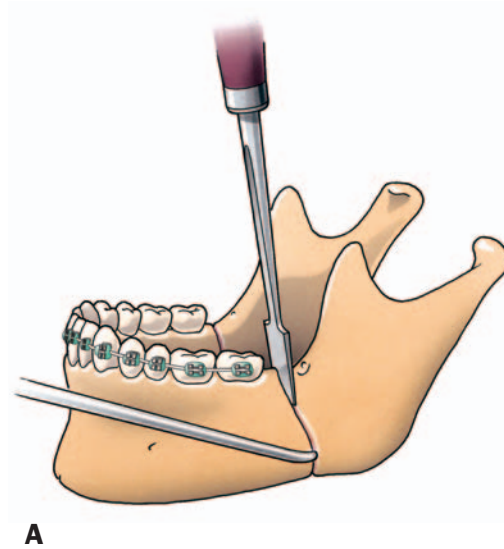


FIGURE 28-10 A, Greenstick fracturing of the mandible. B, On final fixation, the hinge of the posterior fixation unit must be positioned perpendicular to the occlusal plane.

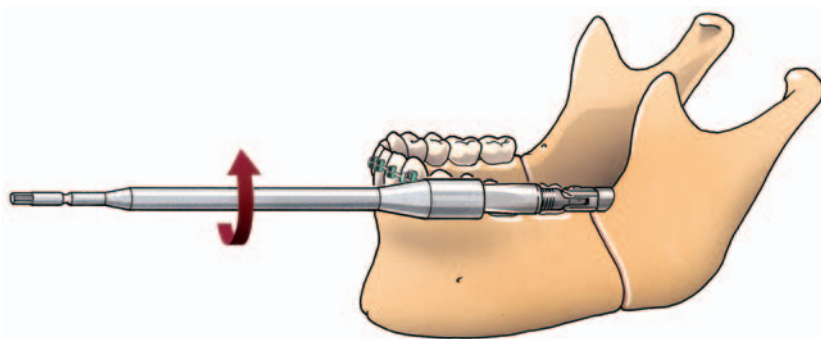
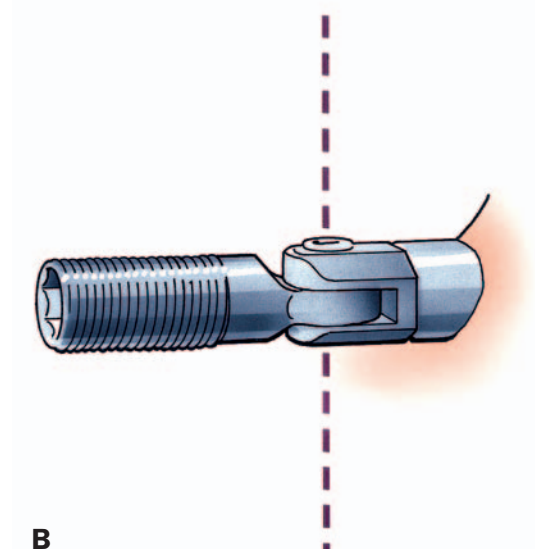


FIGURE 28-11 Placement of the distraction unit.

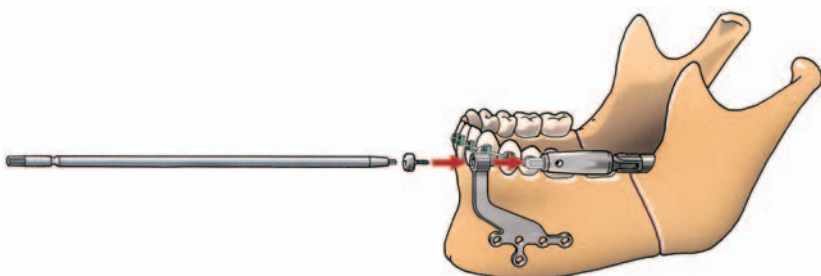


FIGURE 28-12 The anterior fixation unit is bent and placed in position, after which the protection screw is applied.

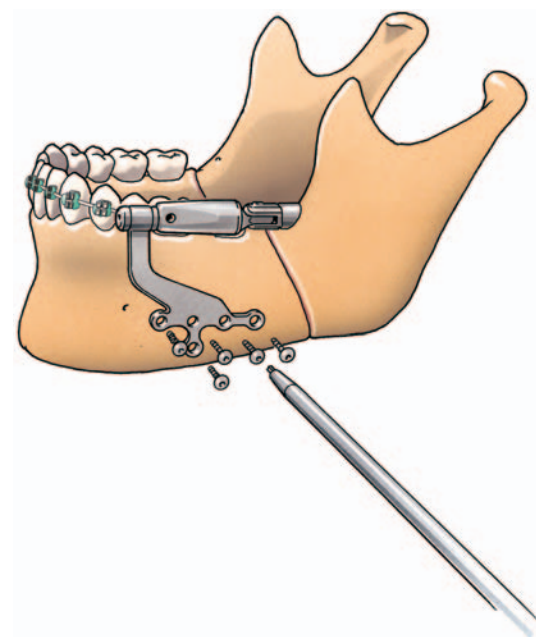


FIGURE 28-13 The anterior fixation unit is fixed with monocortical osteosynthesis screws.

- 11. The mucous membrane is sutured in the usual way.
- 12. When the necessary lengthening is achieved, a blocking screw is not mounted, but the patient is instructed to activate when sagging is noticed. In this way, early relapse is corrected. Rotation of the PFU is seen in 10% of the cases and occasionally needs correction by manipulation.
- 13. MD-DOS is removed using infiltration anesthesia after 2 months.

It is important that the brackets or surgical arch bars be in place. They have been omitted in the drawings for clarity.

Case Report

A 27-year-old male patient with mandibular hypoplasia and a deep bite was referred, at his own request, for mandibular lengthening using local anesthesia (Figure 28-14). Surgery in January 2000 was uneventful. The mobilization of the segments was complete at the righthand side and in a greenstick fashion on the lefthand side. Five millimeter-long spacers and 15 mm PFUs were used, and the standard (small) anterior fixation unit with four monocortical screws at each side (Figure 28-15). Activation started after 1-week latency at a rhythm and a rate of one-time $\frac{1}{3}$ mm daily. The final position was reached after 14 days of activation. The patient was seen in March 2000 with continued small overcorrection and correct midlines. The devices were removed using local anesthesia 3½ months after installment. The file was closed in November 2000, with the patient wearing provisional dentures (Figure 28-16).

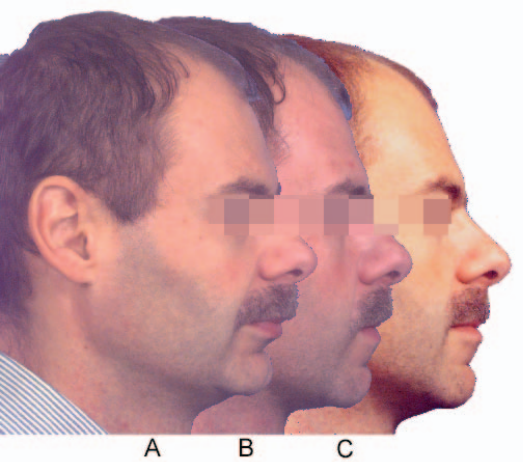


FIGURE 28-14 Case report: facial profile views. A, Pretreatment; B, 3.5 months postoperatively, with the MD-DOS device in situ; C, 10 months postoperatively.

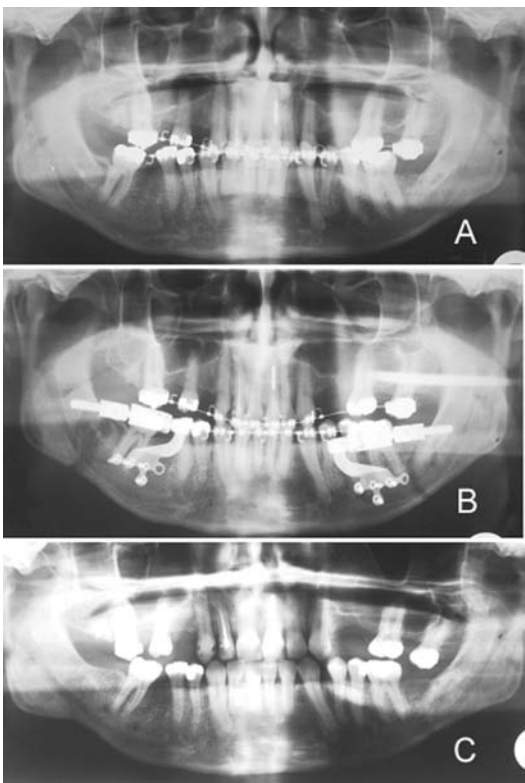


FIGURE 28-15 Case report: orthopantomograms. A, Pretreatment; B, 2 weeks postoperatively, with ongoing activation of the distractors; C, 10 months postoperatively.



FIGURE 28-16 Case report: occlusal views. A to C, Pretreatment occlusion; D to F, at the end of the activation period; G to I, 10 months postoperatively, with provisional dentures.

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Mandibular Lengthening by Distraction Osteogenesis

David A. Walker

The sagittal split osteotomy has been used successfully in the treatment of modest mandibular retrognathia and is well documented in the literature.¹ Problems can arise with this procedure when extreme lengthening is required or when unusual osseous anatomy is present. Distraction osteogenesis for limb lengthening was pioneered in the modern era by Dr. Gavriel Ilizarov, a Russian physician.²⁻⁴ Distraction osteogenesis techniques have been successfully applied to the maxillofacial region since 1992.⁵⁻⁸

Distraction osteogenesis is an innovative technique for lengthening the mandible extreme distances while creating new bone, with good stability. Conventional orthognathic surgery for lengthening of the mandible to extreme distances frequently requires an external approach, autologous bone grafting with potential donor-site morbidity. These large acute advancements obtained with orthognathic procedures are prone to skeletal relapse.^{9,10}

This chapter reviews the indications, biologic basis, and anatomic considerations in distraction osteogenesis. The distraction surgical technique and clinical cases are presented. The advantages and disadvantages of distraction osteogenesis are reviewed, as well as the morbidity, costs, and orthodontic considerations.

Indications for Mandibular Distraction Osteogenesis

Mandibular distraction osteogenesis techniques are indicated in situations in which traditional surgical procedures have developed difficulties, such as the amount of acute lengthening of the mandible or the limited amount and configuration of bone present (Table 29-1).

Mandibular distraction osteogenesis is indicated when severe mandibular retrognathia or micrognathia is present. Mandibular advancements of 10 to 20 mm are difficult to perform with a sagittal split osteotomy. Rudimentary small mandibles have limited bone stock, and long sagittal splits are required (technically more difficult) to allow bony overlap with large

Table 29-1 Indications for Mandibular Distraction Osteogenesis

Severe mandibular retrognathia/micrognathia
Craniofacial syndromes: Hemifacial Microsomia, Treacher Collins syndrome, Nager syndrome, Pierre Robin sequence
Severe mandibular asymmetry
Post-traumatic deficient mandibular growth and temporomandibular joint ankylosis
Revision mandibular orthognathic surgery
Mandibular retrognathia with temporomandibular joint disease or juvenile rheumatoid arthritis
Mandibular retrognathia with obstructive sleep apnea
Mandibular defects from tumor resection

advancements. Acute mandibular lengthening of 10 to 20 mm requires significant stripping and stretching of the musculature and soft tissue attached to the mandible, with an increased chance of skeletal relapse.^{9,10} Distraction osteogenesis techniques allow distraction histogenesis, gradual soft tissue adaptation, and proliferation in response to mandibular lengthening.

Pediatric and adult patients with craniofacial syndromes (Hemifacial Microsomia, Treacher Collins syndrome, Nager syndrome, and Pierre Robin sequence) have rudimentary unusual bone and soft tissue anatomy, which presents difficulty in performing conventional osteotomies. Mandibular distraction osteogenesis techniques are indicated in this patient population, which allow simple osteotomy design and significant mandibular lengthening, without the need for bone grafting and potential donor-site morbidity.

Severe mandibular asymmetry creates difficulties in adaptation of the sagittal split osteotomy segments as flaring of the ramus occurs on one side and medial ramus displacement occurs on the contralateral side. Although other osteotomies can be used, these difficult skeletal movements are intensified when significant mandibular advancement is added to the asymmetric movement. Temporomandibular joint displacement can occur as a result of these complex asymmetric skeletal movements, particularly when rigid internal fixation is applied.¹¹ Mandibular distraction osteogenesis techniques are indicated in severe mandibular asymmetry as a linear osteotomy is used, which avoids torquing of the

proximal segment and temporomandibular joint. Slow, gradual mandibular lengthening allows potential soft tissue and temporomandibular joint adaptation.¹²

Severe mandibular retrognathia can also develop following maxillofacial trauma, such as mandibular fractures, which may have occurred in childhood or adulthood. Condylar fractures occurring at an early age can result in subsequent bony and/or fibrous temporomandibular joint ankylosis and/or deficient mandibular growth. Temporomandibular joint ankylosis in a growing child would typically be treated in an effort to maintain jaw function and improve growth.

Temporomandibular joint ankylosis in a growing child may best be managed with costochondral growth center transplantation, but deficient growth can still occur. Distraction osteogenesis is indicated in post-traumatic patients with asymmetric growth, with abnormal bony anatomy present and anticipated difficulty in performing osteotomies. Distraction osteogenesis techniques have been used in temporomandibular joint ankylosis patients with a combination of reestablishing articulation of the ramus with temporal bone and significant lengthening of the mandible.¹³

Complications associated with mandibular advancement using the sagittal split osteotomy have been reported, including bad split, malunion, fibrous union, nonunion, skeletal relapse, and temporomandibular joint resorption.¹⁴ These complications can be intensified if significant mandibular advancement was attempted with

intraoperative or postoperative problems. Mandibular distraction osteogenesis techniques are indicated in revision orthognathic surgery in areas of previous osteotomies with unusual bony anatomy present.

Conventional treatment of patients with mandibular retrognathia with juvenile rheumatoid arthritis or temporomandibular joint disease presents a different set of difficulties. These patients may be treated with conventional osteotomies, costochondral rib grafts, and/or alloplastic temporomandibular joint reconstruction in the nongrowing patient. Sagittal split advancement of the mandible in these patients with significantly abnormal joints may result in further temporomandibular joint resorption and the need for revision surgery. Distraction osteogenesis is indicated in patients with these entities as slow, gradual loading of the temporomandibular joints may be less deleterious than acute stretching and acute loading of the temporomandibular joints via conventional surgical procedures. Furthermore, unusual bony anatomy is often present in patients with juvenile rheumatoid arthritis, who may require other osteotomies with bone grafting. Distraction osteogenesis avoids the bone grafting and potential donor-site complications in these patient populations.

Pediatric and adult patients can present with mandibular retrognathia with obstructive sleep apnea. In the pediatric population from birth to 6 years, conventional osteotomies are difficult to perform owing to available bone stock and the presence of other important structures, such as developing tooth buds and inferior alveolar neurovascular bundle. Distraction osteogenesis is indicated in this early pediatric age group to improve the airway and avoid permanent tracheostomy.

In patients with obstructive sleep apnea, the limiting factor of treatment is the degree of mandibular advancement required. Distraction osteogenesis allows greater mandibular lengthening than acute skeletal movements, with concomitant soft tissue change. Additional osteotomies may be required in the maxilla and chin to facilitate maximum change in soft tissue stretch in these challenging patients.

Distraction osteogenesis is also indicated for mandibular defects from tumor resection. These types of tumor defects frequently require autologous hip, rib, or fibula grafting. Distraction osteogenesis reconstitutes the mandible with vital bone and avoidance of bone grafting and donor-site morbidity.

Distraction Osteogenesis Device Considerations

Distraction osteogenesis devices and techniques have been investigated and refined through

animal research and clinical applications. Early animal distraction osteogenesis studies demonstrated mandibular distraction osteogenesis to be an effective method to lengthen the mandible and create new bone (Figure 29-1).^{15,16} Three-dimensional vector control of the path of distraction became important to achieve desirable occlusal outcomes. Multidirectional distraction osteogenesis devices have evolved to allow adjustment of the vector distraction after placement of the device, which allows improved occlusal outcomes (Figure 29-2).¹⁶

Initially, mandibular distraction osteogenesis devices were unidirectional external devices, which have subsequently evolved to three-dimensional external devices. Although external devices are effective in mandibular distraction osteogenesis techniques, complications such as external skin scars, pin loosening, pin tract infection, and shorter consolidation times make them less attractive.

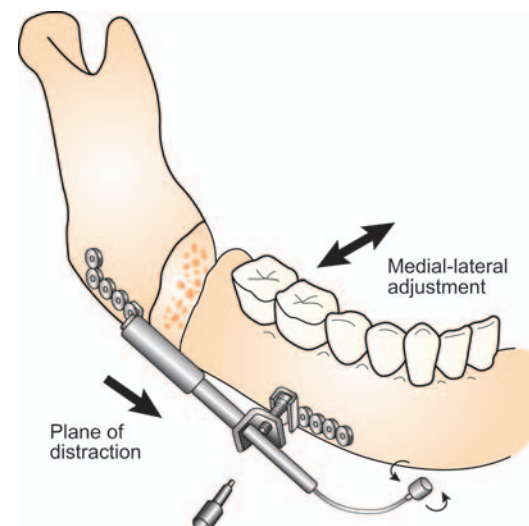


FIGURE 29-2 Bidirectional telescopic mandibular distractor able to distract longitudinally and medially or laterally (Innova Life Sciences, Toronto, ON).

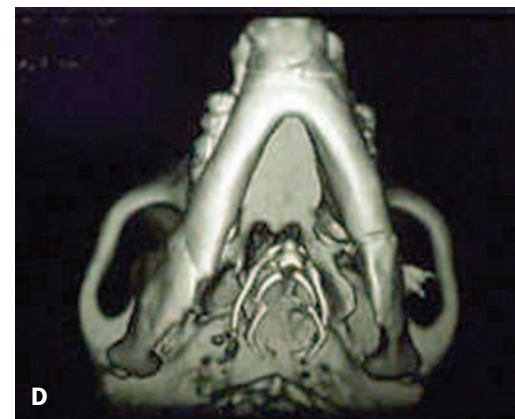
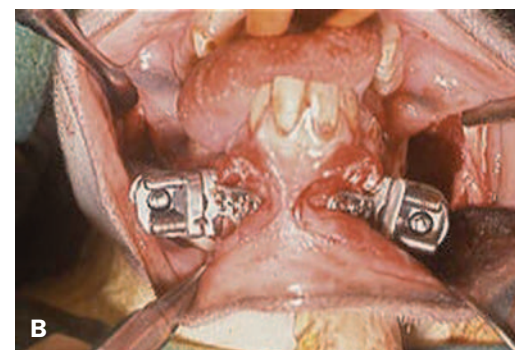


FIGURE 29-1 A, Animal research and development of bidirectional telescopic mandibular distractor using sagittal ramus osteotomy. B, Bilateral device placement from a transoral approach. Note the symmetry of the distraction devices. C, Three-dimensional computed tomographic scan reconstruction of animal body ramus osteotomy, 2½ months postdistraction. D, The same animal, 13 months postdistraction. Note that the distraction bony regenerate is virtually imperceptible with host bone. (Figure 29-1B has been reproduced from Walker,¹⁶ with permission from Mosby, Inc.)

Buried unidirectional and subsequently multidirectional intraoral distraction osteogenesis devices have overcome the obstacles of external devices and have proved to be successful.¹⁷⁻²⁰ Intraoral distraction osteogenesis devices avoid external skin scar of distraction, offer good cosmesis and patient acceptance, and allow consolidation times of an appropriate length. Intraoral devices are either tooth-borne, bone-borne, or hybrid. Bone-borne devices offer the greatest stability, whereas tooth-borne devices result in dental and osseous movements.

Distraction Osteogenesis Biologic Basis and Technique

Integral to the overall success of mandibular lengthening with distraction osteogenesis is an understanding of the biologic basis of the technique, with proper preoperative planning and vector selection.²¹ Distraction osteogenesis involves an osteotomy, a latency period, a distraction device activation period, a bony consolidation period, and a bony remodeling period.^{22,23} The distraction osteogenesis intraoral devices are contoured, and the osteotomies are partially completed. The distraction osteogenesis devices are then stabilized with bicortical or monocortical screws, the osteotomies are completed, device activation is undertaken to ensure movement of the bony segments, and then the device is backed down to the zero position (Figure 29-3).

Typically, a linear osteotomy is created through the mandible with burs or saws, except in the location of the inferior alveolar neurovascular bundle. The osteotomy is completed with osteotomes, creating a fracture. Corticotomy and other osteotomies have also been used in mandibular distraction osteogenesis.^{24,25}

The latency period allows resolution of inflammation secondary to the osteotomy and surgical placement of the device. It also allows initial organization of the hematoma and induction of pleuripotential mesenchymal cells and endosseous and periosteal cells into fibroblasts and osteoblasts. During this time, type I collagen is laid down and osteoid production occurs. The latency period ranges from 0 to 10 days, although the most common latency period is 5 days, for children and adults. A shorter latency period is used in neonates and infants.

The distraction process, or callus manipulation, occurs at a rate ranging from 0.5 to 2 mm a day. The rate will depend on the age of the patient and the type of osteotomy. The gold standard for clinical distraction osteogenesis is 1 mm a day, divided into two or four activations per day. The distance of distraction is determined by the amount of skeletal and occlusal change desired. Transoral activation arms are typically removed under local anesthetic and/or sedation at the completion of the distraction.

The consolidation period in adults should be a minimum of 3 months and can be extended up

to 6 months as needed. Consolidation time is related to the magnitude of the distraction distance and the age of the patient. Shorter consolidation times have been used in patients from birth to 6 years of age. Adequate stability of the bony segments is important during distraction and the consolidation period to allow an optimum bony regenerate to occur. Timing of distraction regenerate consolidation is documented by radiographs, sonograms, or computed tomographic (CT) scans. Distraction device removal can be carried out on an outpatient basis under sedation or general anesthesia, particularly if additional ancillary orthognathic or surgical procedures are being performed. Further bony remodeling of the distraction regenerate under function will occur up to 1 year or longer after the period of distraction. The regenerated bone will ultimately be virtually indistinguishable from the adjacent bone and will withstand normal physiologic loading.

Distraction Vector Selection

Preoperative three-dimensional vector selection is important to achieve a predictable esthetic and functional outcome following mandibular lengthening with distraction osteogenesis. Diagnostic aids in selecting the distraction vector include clinical evaluation; panoramic, lateral, and posteroanterior cephalometric radiographs; and CT scan with three-dimensional reconstruction.

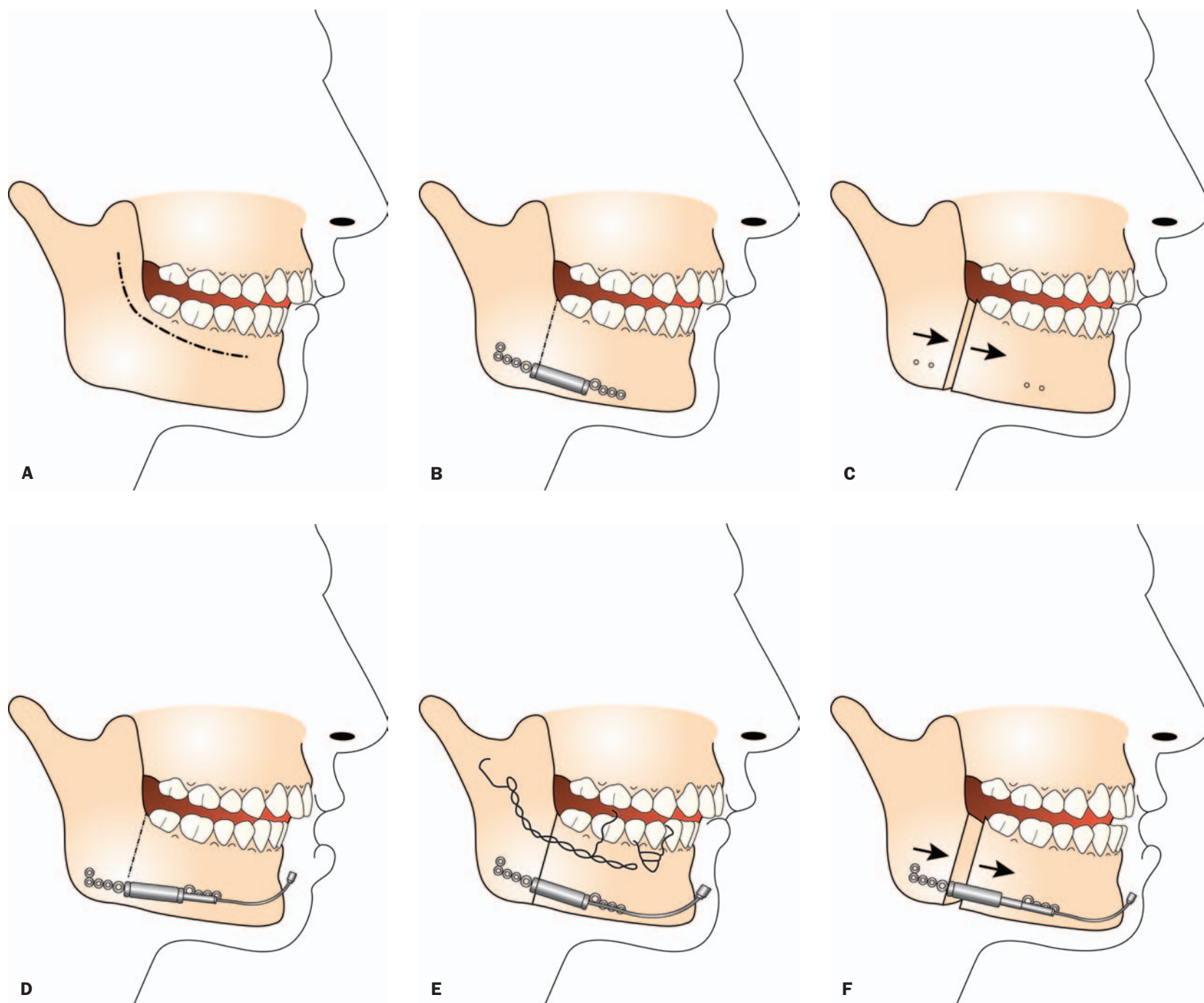


Figure 29-3 A, There is significant mandibular retrognathia with large overjet. A standard incision along the external oblique ridge and traversing out in the vestibule with subsequent subperiosteal dissection exposes the posterior lateral aspect of the mandible. B, Contouring and initial stabilization of device with monocortical screws, 2 placed anteriorly and 2 placed posteriorly. The location of the osteotomy is indicated. C, The osteotomy has been completed and the segments of the mandible are completely mobilized. D, The device has been reappplied with monocortical or bi-cortical screws, 3-4 anteriorly and 4-5 posteriorly. The device is activated to confirm freedom of movement of segments. E, Standard closure of the incision with vertical and/or horizontal mattress sutures and a running suture. F, The device is activated with the rigid or flexible activation arm with two half turns daily for a total activation of 1.1 mm of distraction. Body of the mandible is distracted anteriorly until the malocclusion is corrected.

Stereolithographic models are also useful for selection of osteotomy location, preoperative distraction device contouring, and vector selection when unusual anatomy is present. Model surgery using occlusal casts mounted on a semiadjustable articulator, in conjunction with cephalometric analysis and lateral and posteroanterior cephalometric prediction tracings, may further help define the vector and distance of distraction. Video imaging linked to cephalometric prediction tracings may allow complete visualization of the treatment goals. In bilateral mandibular distraction osteogenesis, the vector is typically parallel to the occlusal plane and close to the sagittal plane. Variations will occur in vector selection in asymmetric mandibles. Multidirectional distraction devices provide the opportunity to adjust the vector of distraction during the distraction process as needed.^{21,26}

Orthodontic Considerations in Distraction Osteogenesis

Patients requiring distraction osteogenesis frequently require a team approach involving a surgeon, an orthodontist, a family dentist, a family physician, and additional medical and dental specialists as required. Orthodontists aid in growth monitoring and diagnosis in these complex patients.

Orthodontic therapy is frequently required to enhance the occlusal outcomes of distraction osteogenesis. Orthodontic therapy for the

nongrowing patient typically involves preparatory arch alignment, coordination, and decompensation. Maxillary arch expansion is usually required to accommodate the mandible as it is advanced significant distances. After distraction osteogenesis, further detailing and alignment and finishing of the occlusion are typical. Occasionally, distraction osteogenesis can be employed early in treatment with subsequent ancillary orthognathic surgical procedures at the time of removal of the distraction osteogenesis device.

Bilateral mandibular osteogenesis for lengthening can be symmetric or asymmetric. Unilateral mandibular distraction osteogenesis will always be asymmetric. The asymmetric movements will require greater orthodontic tooth movement and finishing postdistraction.

Distraction osteogenesis treatment from birth to age 6 years rarely requires orthodontic intervention. These severe deformities require treatment at this early age, which is frequently related to improving a compromised airway. Distraction osteogenesis techniques in the 6- to 12-year-old age group are usually employed in severe skeletal deformities with functional and psychosocial implications. Postdistraction osteogenesis functional appliance therapy can aid in correction of occlusal crossbites and canted occlusal plane during the mixed dentition. These interventions can frequently decrease the amount of surgery required at a later date.

Infants and children with severe deformities who undergo distraction osteogenesis treatment

during growth will likely require secondary distraction techniques or further orthognathic surgical procedures at or near the completion of skeletal growth.¹⁰

Advantages of Distraction Osteogenesis for Mandibular Lengthening

The most striking feature of mandibular lengthening with distraction osteogenesis is the significant distance of lengthening that can be achieved with new bone formation. New bone is created during distraction, during a cascade of cellular and molecular events. This membranous bone, parallel to the distraction direction, matures into bone similar to the adjacent bone (cortical bone surrounded by intramedullary cancellous bone) during consolidation.^{15,24} Mandibular lengthening with distraction osteogenesis of 10 to 30 mm has been reported with very good success.

Conventional surgical treatment for mandibular advancement of 10 to 30 mm typically requires an external approach to the mandible and osteotomy with a subsequent autologous hip or rib graft. Distraction osteogenesis techniques for this type of lengthening are undertaken from an intraoral approach with osteotomy and distraction device placement. Distraction devices are removed after a suitable time of consolidation (Figure 29-4 and 29-5).

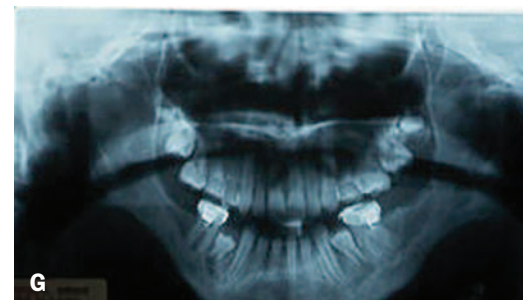
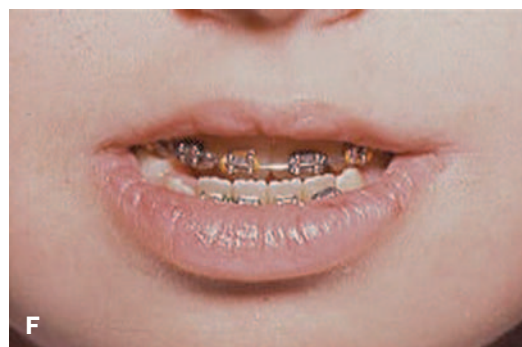


FIGURE 29-4 A, An 11-year-old female patient with micrognathia. B, Profile 5 months postdistraction, 14 mm on the left side, 12 mm on the right side. C, Preoperative cephalometric radiograph. Note the marked mandibular micrognathia and limited posterior pharyngeal air space. D, Cephalometric radiograph; 14 mm of distraction of the mandible with overcorrection to a Class III position, bidirectional telescopic mandibular distractor. E, Occlusion at the completion of distraction of 14 mm of lengthening, overcorrected Class III. F, Final occlusion after further orthodontic therapy. G, Panoramic radiograph, 5 months postdistraction. Note the distraction regenerate in the left and right body ramus juncture. (Figure 29-4G has been reproduced from Walker D¹⁶ with permission from Mosby, Inc.)



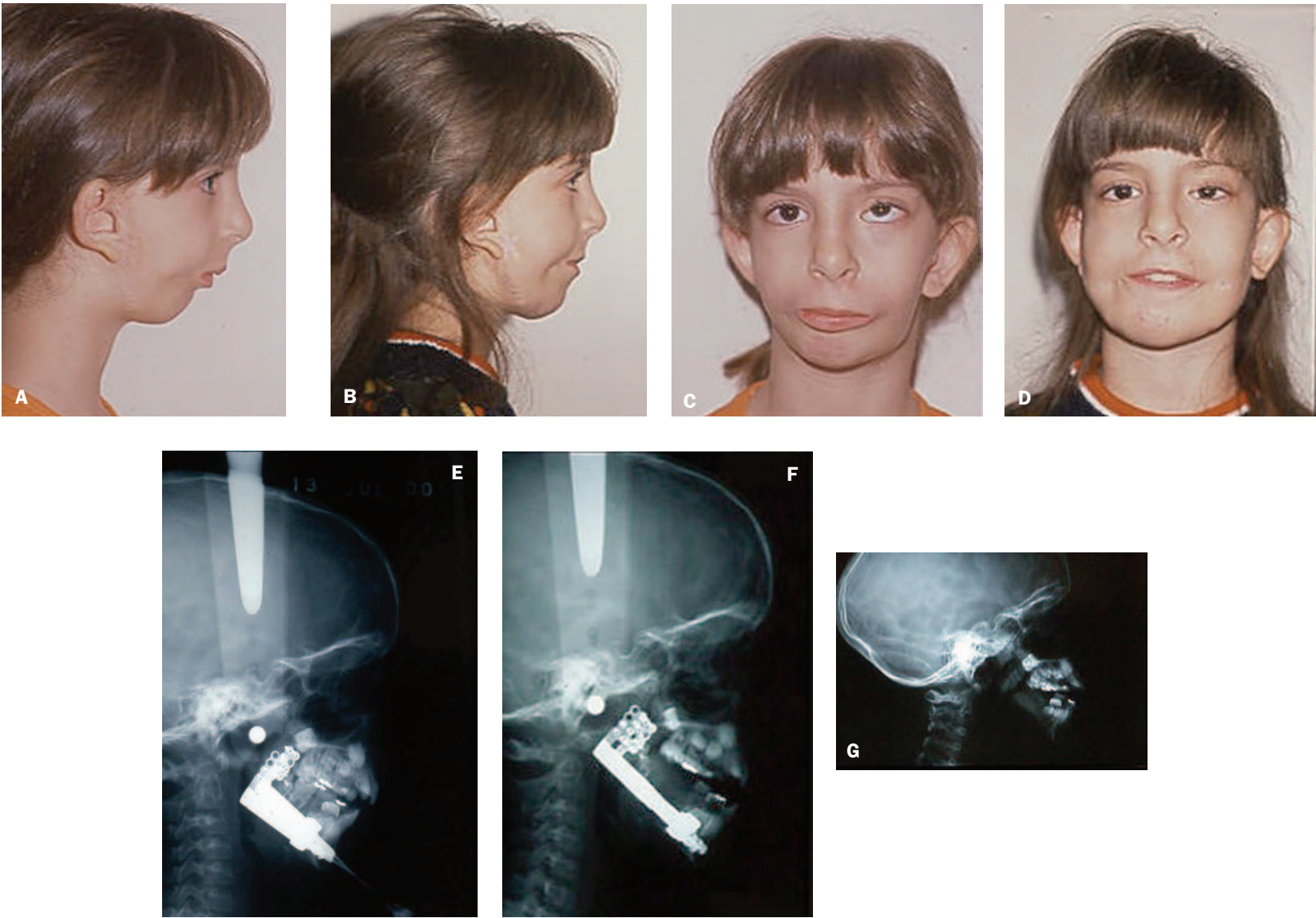


FIGURE 29-5 A, Profile of a 7-year-old patient with Goldenhar's variant of hemifacial microsomia. Previous mandibular distraction at age 1 year. B, Profile 4 months after 17 mm distraction mandibular lengthening on the right side and 10 mm lengthening on the left side with the bidirectional telescopic mandibular distractor (BTMD). C, Facial view predistraction demonstrating facial asymmetry to the right. D, Facial view 4 months postdistraction with good mandibular symmetry. E, Lateral cephalometric radiograph immediately following BTMD placement, prior to distraction. F, Lateral cephalometric radiograph after completion of distraction, 17 mm on the right side and 10 mm on the left side. G, Lateral cephalometric radiograph 5 months postdistraction; note distraction regenerate at the body ramus junction.

Another striking feature of mandibular distraction osteogenesis is soft tissue histogenesis. This is a combination of gradual stretching of the soft tissues and cellular proliferation. An increased number of myocytes, along with adaptations in sarcomere length, have been reported in muscle in response to distraction osteogenesis.^{27,28} These favorable adaptive changes maintain the soft tissue attachments to bone; hence, there is a greater blood supply to the distraction site and mandible than with conventional osteotomies. These events also allow greater mandibular lengthening with minimal or no relapse (Table 29-2).

Table 29-2 Advantages of Distraction Osteogenesis for Mandibular Lengthening
Allows greater mandibular lengthening of 10–30 mm
Can be applied to unusual bony and soft tissue anatomy
Allows slow gradual soft tissue adaptation to extreme mandibular lengthening
Minimal to no skeletal relapse after extreme mandibular lengthening
Can be applied to neonates, infants, and pediatric patients with obstructive sleep apnea
Less invasive surgery compared with bone-grafting procedures
Avoids intermaxillary fixation
Avoids bone grafting and potential donor-site morbidity
Can be used for mandibular widening
Potential for fewer adverse temporomandibular joint effects in response to asymmetric lengthening
Decreased length of hospital stay and cost compared with bone grafting
Less chance of blood transfusion

Mandibular lengthening with distraction osteogenesis techniques has significant advantages over conventional surgical approaches to the mandible with patients with significant temporomandibular joint problems. These include significant degenerative joint disease, osteoarthritis, and rheumatoid arthritis. Distraction osteogenesis is an advantage in these patients even if moderate lengthening of the mandible is anticipated.

It is documented that acute loading of the temporomandibular joint from conventional mandibular osteotomies and lengthening can exacerbate temporomandibular joint problems.^{14,29} The amount of stripping of the periosteum and musculature off the proximal segment may decrease its vascularity and result in further condylar remodeling and/or resorption.

Patients with idiopathic condylar resorption after mandibular osteotomy are frequently treated with camouflage maxillary surgery in an attempt to mask the mandibular retrognathism. Distraction osteogenesis allows treatment of significant mandibular retrognathism secondary to idiopathic condylar resorption. There is a need for less surgical access to create a linear body-ramus osteotomy and apply intraoral distraction devices, with potentially less disturbance to soft tissue vascularity, than with the usual mandibular osteotomy. Distraction osteogenesis results in gradual loading of the problematic temporomandibular joints rather than the

acute joint loading associated with acute mandibular advancement.

Patients with juvenile rheumatoid arthritis may have had previous surgery or present *de novo*. The unusual condylar resorption, short ramus height, and severe micrognathia present difficult problems for performing typical mandibular advancement surgery. Surgical modalities that are frequently used include an inverted L or C osteotomy and simultaneous bone grafting from an external approach. Alternatively, costochondral grafts or replacement with alloplastic temporomandibular joints has been reported.²⁹ Distraction osteogenesis can be used to create increased ramus height and mandibular body length without the need for bone grafting. Greater distances can be achieved in lengthening of the mandible, with secondary favorable soft tissue adaptation and gradual loading of the problematic temporomandibular joints (Figure 29-6).

There is minimal evidence of significant remodeling of the temporomandibular joint secondary to mandibular lengthening with distraction osteogenesis documented in animal studies.^{30,31} Use of bidirectional and tridirectional distraction devices offers improved vector control during mandibular distraction and appears to cause less remodeling of the temporomandibular joints than unidirectional devices.³²

Another advantage of distraction osteogenesis techniques is that no intermaxillary fixation is required. This is true 100% of the time. Intermaxillary fixation is occasionally used in conventional surgical procedures, particularly if costochondral rib grafts are applied, if large acute surgical movements are undertaken, or if a lack of stability of rigid internal fixation is evident at the time of surgery.

Severe mandibular retrognathia also can be a contributing factor in obstructive sleep apnea. The classic picture of daytime hypersomnolence, disrupted sleep patterns, and subsequent cardiovascular and neurologic sequelae can be significant. Surgical advancement of the mandible and/or maxilla in adult patients with obstructive sleep apnea has resulted in significant improvements in their respiratory disturbance index, often eliminating the need for nasal continuous positive airway pressure.^{33,34} The limiting factor with traditional surgical mandibular advancement is the distance of advancement and the potential for relapse. Distraction osteogenesis provides an opportunity to provide greater lengthening of the mandible, with potentially greater stability and less relapse compared with conventional surgery.³⁵ These techniques can be applied to the mandible and the maxilla to provide significant resolution or correction of obstructive sleep apnea. The gradual lengthening of the mandible can be titrated by polysomnography to the desired amount for effective airway change.



FIGURE 29-6 A, A 17-year-old patient with previous radiation therapy at age 1 year and subsequent chemotherapy until age 11 years for histiocytosis X. The patient was disease free, with mandibular asymmetry to the left, 1 year following costochondral rib graft to the left ramus temporomandibular joint. B, Facial view after distraction lengthening of 16.5 mm with the bidirectional telescopic mandibular distractor (BTMD). C, Facial view 2 months after Le Fort I unilateral downgraft, genioplasty, and left angle onlay hip graft removal of the BTMD (6 months postdistraction). D, Profile showing severe micrognathia. E, Profile after 16.5 mm distraction lengthening on the left side and 9.1 mm lengthening on the right side with the BTMD in situ. F, Profile after Le Fort I, genioplasty, hip graft, and removal of the BTMD. G, Predistraction occlusion. H, Post-treatment occlusion. I, Lateral cephalometric radiograph pretreatment demonstrating severe micrognathia. J, Lateral cephalometric radiograph after 16.5 mm lengthening with the BTMD with intentional overcorrection to Class III occlusion. K, Lateral cephalometric radiograph after Le Fort I osteotomy genioplasty, hip graft, and removal of the BTMD.

Mandibular distraction osteogenesis techniques are less invasive than conventional surgical procedures and allow early intervention at a young age, particularly in severe craniofacial syndromes and in patients with obstructive sleep

apnea (Figure 29-7). Distraction osteogenesis techniques have been successful in newborn patients with craniofacial syndromes with obstructive sleep apnea.³⁶ These techniques avoid the option of permanent tracheostomy in these

patients, thus decreasing the overall long-term cost of care and potential complications with permanent tracheostomies.

Many patients with severe mandibular retrognathia present with dentoalveolar

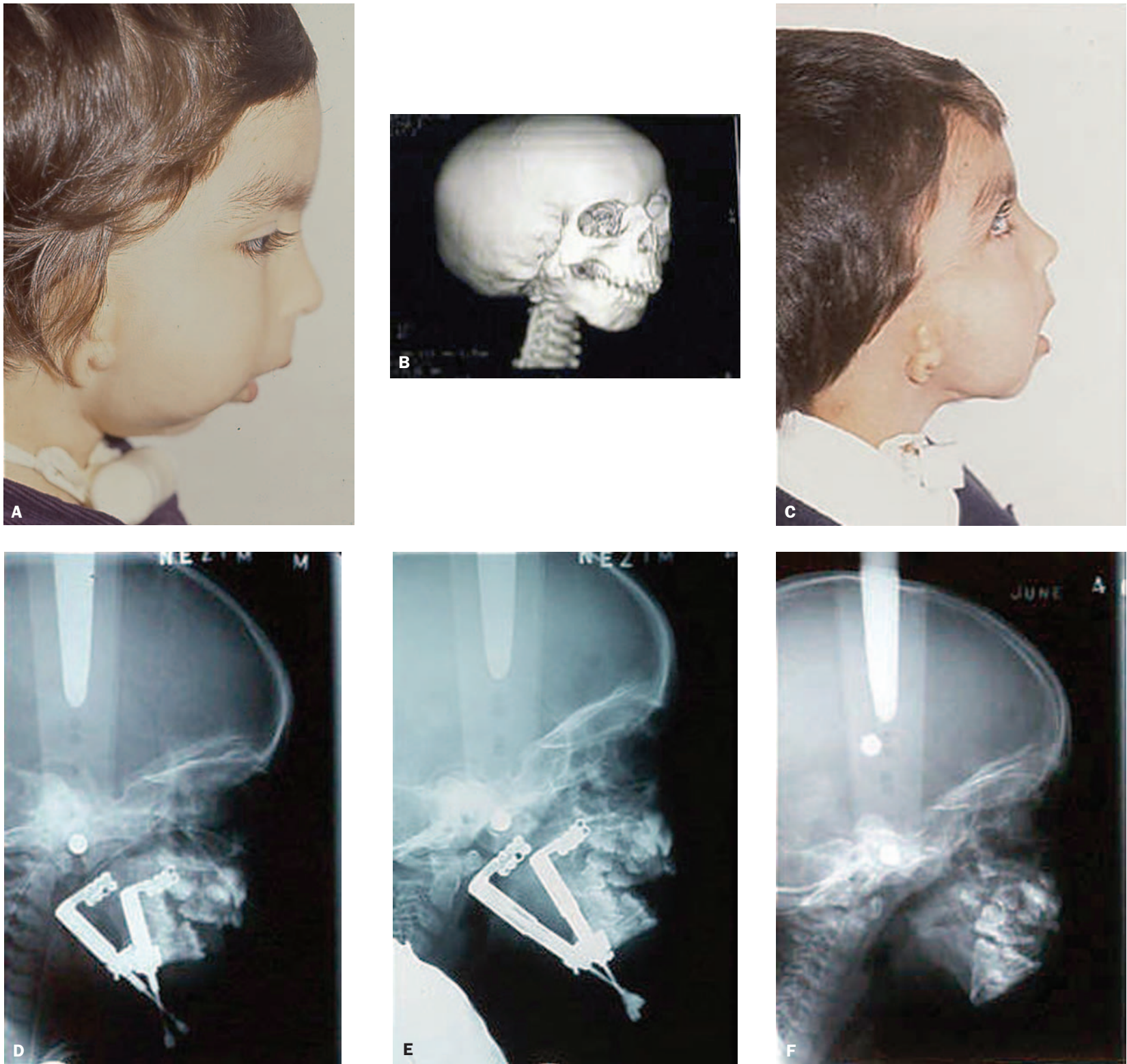


FIGURE 29-7 A, A 5-year-old patient with Goldenhar's variant of hemifacial microsomia who is tracheostomy dependent for obstructive sleep apnea. B, Computed tomographic scan; three-dimensional reconstruction of marked mandibular hypoplasia, ankylosis of the right ramus, and zygoma. C, Four months following mandibular distraction osteogenesis, lengthening of 17 mm on the right side and 15 mm on the left side; the sleep study confirmed resolution of obstructive sleep apnea. D, Cephalometric radiograph immediately following bidirectional telescopic mandibular distractor (BTMD) placement. E, Cephalometric radiograph immediately postdistraction of 17 mm of lengthening of the mandible (BTMD). F, Six months postdistraction. Note the stability and length of the distraction regenerate.

crowding and narrow, constricted mandibular arches. Traditionally, this has been treated by dental extractions for arch alignment and coordination, in preparation for surgical movement of the mandible. This may cause occlusal difficulties, particularly if a transverse skeletal deficiency of the mandible is present. Buccolingual transverse discrepancies in occlusion may then be present after mandibular advancement. Mandibular widening by distraction osteogenesis following a midline symphysis osteotomy creates increased width, arch length, and available space for correction of dentoalveolar crowding (Figure 29-8).³⁷ Simultaneous mandibular widening and

advancement can be undertaken for correction of the three-dimensional occlusal and skeletal problems associated with the severely retrognathic mandible.

Distraction osteogenesis techniques for mandibular lengthening offer a decreased length of hospital stay and therefore decreased cost to the health care system compared with bone-grafting procedures. After autologous hip or rib grafting, occasional intensive care unit admission is required and hospital stay is prolonged owing to donor-site discomfort, the ability to ambulate, and the return to a reasonable level of function prior to discharge from the hospital.

Distraction osteogenesis techniques offer less chance of blood transfusion compared with osteotomies and conventional bone grafting. This is particularly true in pediatric patients, in whom decreased operative time and decreased surgical sites offer less chance of blood transfusion and decreased hospital stay. Extraoral surgical approaches with osteotomies, coupled with harvesting autologous hip or rib grafts, can result in significant blood loss, which may require blood transfusion to maintain adequate tissue perfusion and oxygenation. Currently, blood bank protocols provide a relatively safe option of blood transfusion, although reports still exist of rare



FIGURE 29-8 A, Patient undergoing simultaneous maxillary and mandibular widening with distraction osteogenesis, maxillary constriction. B, Le Fort I segmental distraction osteotomy with midline osteotomy. C, Maxillary distraction widening of 9 mm. D, One year postdistraction after orthodontic alignment for correction of dentoalveolar crowding. E, Skeletal transverse deficiency of the mandible, with crowding. F, Intraoperative parasymphysis osteotomy for distraction. G, Completion of 7 mm of parasymphysis distraction widening. H, After arch alignment coordination 5 months postdistraction widening. I, Posterior-anterior cephalometric radiograph at completion of 9 mm maxillary and 7 mm mandibular widening. J, Posterior-anterior cephalometric radiograph 5 months postdistraction showing distraction regenerate.

transmission of human immunodeficiency virus (HIV) (1 in 500,000 transfusions) and hepatitis B and C (1 in 100,000 transfusions).³⁸

Relapse Considerations in Orthognathic Surgery and Distraction Osteogenesis

An average of 2 mm and up to 30% of sagittal relapse have been reported following mandibular advancement using bilateral sagittal split osteotomy (BSSO) and wire fixation.^{9,39} Relapse is reported as less when rigid internal fixation is used. The greater the acute lengthening, the greater is the propensity toward relapse. Advancements of greater than 10 mm are more prone to skeletal relapse, which can occur at the osteotomy site or at the mandibular condyle (Figure 29-9).³⁹

Rare occurrences of relapse have been reported with mandibular lengthening by distraction osteogenesis. This is attributable to the use of external devices and inadequate time for consolidation of the distraction regenerate or to device loosening.¹⁰ Appropriate distraction device stability and an adequate time of bony consolidation are important for a successful distraction regenerate to develop.

Relapse after 10 to 20 mm mandibular lengthening with distraction osteogenesis is minimal or nonexistent if an adequate distraction protocol and bony consolidation periods are used.^{16,40} A consolidation period of at least 3 months is indicated for significant mandibular lengthening, with the exact time based on radiographic visualization of cortical bone in the distraction regenerate. Buried intraoral distraction devices offer greater patient acceptance and more adequate time for bony consolidation than external distraction devices.

Another important advantage of mandibular lengthening with distraction osteogenesis is that it avoids bone grafting and potential donor-site morbidity. Bone grafting is frequently carried out through a percutaneous approach, resulting in an external skin scar. Transoral bone grafting can also occur but may have a higher risk of infection. If infection associated with bone grafting occurs, this may result in partial or total loss of the graft, with resultant severe skeletal relapse and instability. Distraction osteogenesis avoids donor sites, including autologous hip, rib, fibula, and cranium. Donor-site morbidity has been reported, including postoperative pain at the hip site, persistent gait disturbance, and paralytic ileus.⁴¹ Complications from the rib graft to harvesting include pneumothorax, postoperative pain, and atelectasis.⁴¹ Complications from harvesting cranial bone grafts include intracranial bleeding, infection, and meningitis.⁴² In general terms, distraction osteogenesis techniques are less

invasive than typical bone-grafting procedures requiring multiple surgical sites.

Disadvantages of Distraction Osteogenesis for Mandibular Lengthening

Distraction osteogenesis requires two surgeries for successful treatment. The initial surgery is osteotomy and placement of a distraction osteogenesis device, which is typically carried out under general anesthesia. Distraction devices are left for a period of bony consolidation for approximately 3 to 6 months. A second procedure is required for removal of the distraction device, which can be carried out under outpatient sedation or outpatient general anesthesia. This can be coordinated with ancillary orthognathic surgical procedures if required.

Distraction osteogenesis does require an increased number of postoperative appointments for appropriate monitoring of distraction. If adjustments to the vector are required postoperatively, this is done during the activation phase. Typically, practitioners monitor distraction patients once or twice weekly depending on patient access. Distraction osteogenesis requires a cooperative patient and/or parents for appropriate activation. Patient noncompliance can result in unfavorable results, as with any type of surgical procedure.

Distraction osteogenesis has a low risk of infection associated with transoral device placement or external device placement. Although infections have occasionally been reported with mandibular distraction osteogenesis, it appears to have a minimal effect on distraction regenerate.¹⁶ This is likely owing to the angiogenesis that occurs during the distraction process. A new blood supply, along with new vital bone, is created during the distraction process, which appears to be relatively infection resistant. Skin scars from external distraction devices are a disadvantage, but these have been overcome with the advent of buried intraoral devices.

There are increased costs of distraction osteogenesis devices compared with typical rigid internal fixation plates or screws. The cost of distraction osteogenesis treatment compared with the cost of sagittal split osteotomy appears to be greater.⁴³ The distraction devices are not reusable, but the overall cost of distraction treatment compared with osteotomies with bone grafting and lengthened hospital stay (possibly the intensive care unit) would be less, even including the cost of distraction devices.

Neurosensory Changes Associated with Mandibular Distraction Osteogenesis

Various neurosensory outcomes have been reported in humans and animals in response

to mandibular distraction osteogenesis. Careful surgical technique during the osteotomy and distraction device placement is important to avoid injury to the inferior alveolar nerve. With the development of buried intraoral devices, permanent injury to the facial nerve has virtually been eliminated.

Clinical reports on sensory changes in the inferior alveolar nerve vary from none^{44,45} to neurosensory deficits ranging from 25 to 50% of patients undergoing mandibular distraction osteogenesis.^{46,47} Action potentials measured during 10 mm of distraction osteogenesis of the mandible in dogs revealed minimal deleterious effects on the inferior alveolar nerve. There were no significant differences in jaw-jerk voltage of the mental nerve between control and unilateral mandibular distraction osteogenesis sites. The authors concluded that these were only mild inferior alveolar nerve injuries secondary to slow traction.⁴⁸ Bilateral mandibular distraction osteogenesis at a rate of 1 mm/d in goats also appeared to be tolerable and safe for the inferior alveolar nerve. However, distraction rates of 2 mm/d may result in significant nerve degeneration.⁴⁹

Nerve function and bilateral mandibular distraction osteogenesis were objectively evaluated in five patients. All inferior alveolar nerves showed improvement in function over the 1-year follow-up period, consistent with or very near presurgery levels.⁵⁰

During the BSSO for mandibular advancement, damage to the inferior alveolar nerve can occur during the osteotomies while splitting the mandible or from medial retraction. The inferior alveolar nerve may be manipulated significantly, particularly if it is partially embedded in the proximal segment and requires decortication and freeing. Application of rigid fixation with cortical screws and/or miniplates may directly injure the inferior alveolar nerve or can create nerve compression injury.^{51,52}

Various authors have reported statistically significant neurosensory injury from the BSSO, depending on the age of the patient, magnitude of advancement of the mandible, and degree of nerve manipulation.⁵³ Other authors have reported permanent changes in inferior alveolar nerve sensation ranging from 15 to 87% at 1 year after osteotomy.⁵⁴ Additionally, increased inferior alveolar nerve damage from screws used for rigid internal fixation, as well as permanently altered lingual nerve sensation, has been reported at 1 year after sagittal split osteotomy.⁵⁵

Clinical experience and a review of the literature indicate that temporary and permanent neurosensory changes can occur with mandibular distraction osteogenesis and with conventional osteotomies for lengthening of the mandible. There is a wide range of reported clinical incidence of permanent altered sensation, which may be related to the surgical technique. However, it

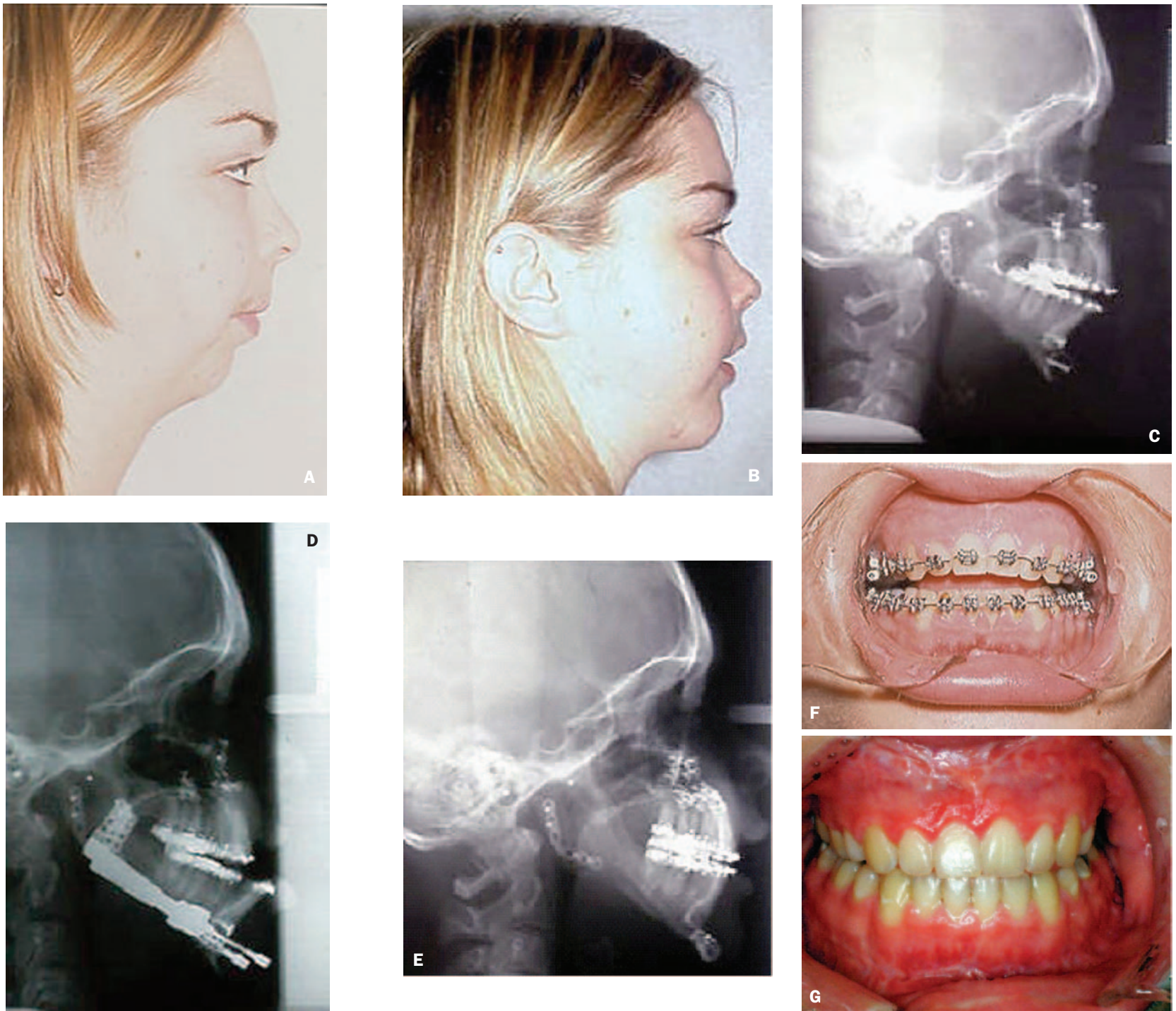


FIGURE 29-9 A, Profile following orthognathic surgical relapse, Le Fort I sagittal split genioplasty (referral from another surgeon). B, Postdistraction lengthening of 15 mm, with revision Le Fort I and genioplasty. C, Cephalometric radiograph following orthognathic surgery. Note the marked skeletal mandibular relapse. D, Cephalometric radiograph after 15 mm of lengthening of the mandible with the bidirectional telescopic mandibular distractor (BTMD); extraction of the first bicuspid with overcorrection. E, Cephalometric radiograph after removal of the BTMD, revision Le Fort I, and genioplasty. F, Following orthognathic surgery occlusion. G, Following distraction and revision of a Le Fort I occlusion.

would appear that distraction osteogenesis techniques for significant mandibular lengthening of 10 to 20 mm may result in fewer neurosensory changes than the conventional BSSO.

Summary

Mandibular lengthening with distraction osteogenesis in patients with severe mandibular retrognathia has significant advantages compared with traditional orthognathic surgical techniques. Multidirectional buried intraoral distraction devices have overcome some of the obstacles of earlier external distraction devices and produce good vector control, occlusion, and esthetic results. The occlusal outcomes are aided by concomitant orthodontic therapy. Distraction osteogenesis techniques do require additional surgical training, a thorough understanding of the biologic process, and careful preoperative planning. Distraction osteogenesis is technique sensitive, and the surgical skills and experience of the surgeon reduce the complication rate and optimize treatment outcomes. Refined distraction osteogenesis techniques for the treatment of severe mandibular retrognathia provide the opportunity for more favorable treatment outcomes compared with traditional surgical procedures, with less morbidity and minimal complications.

Acknowledgments

I would like to acknowledge the collaborative efforts of Dr. Christopher Forrest and Dr. Bryan Thompson in the cases in Figures 29-4, 29-5, and 29-7. I would like to thank Dr David Psutka for performing the rib graft in the case in Figure 29-6. I wish to thank Ms. Goretti Sozinho, who typed the manuscript. I wish to acknowledge Mr. Michael Kehoe from Innova Life Sciences for funding the research and development of the bidirectional telescopic mandibular distractor.

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Sagittal Distraction Osteogenesis of the Mandible: Indications and Technique

Jeffrey J. Moses

The advent of orthognathic surgery revolutionized the treatment of craniofacial deformities. Now commonplace, the technique involves the creation of an osteotomy in an area of bone deficiency, and repositioning the bone into a new, proper orientation. The bone segment is then held in place with rigid fixation to allow for bone healing across the bone gap. If the gap of the osteotomy site is of critical size, then the gap is filled with bone or bone matrix materials to ensure osseous continuity. Traditional orthognathic surgery can be limited in the amount of soft tissue stretch, as the bony segments are moved immediately to the new position. Similarly, the final bone position can be influenced by this local muscle pull, producing relapse either at the level of the osteotomy or in adjacent bony structures including the temporomandibular joint (TMJ).¹⁻³

Distraction osteogenesis (DO) uses similar surgical principles. An osteotomy is created in an area of bone deficiency, and the segments are moved to their final, proper orientation, being held in place until osseous continuity and bone healing are achieved. The primary difference in the distraction technique is that the bone segments are moved slowly over time. Consequently, the forces induced by the local soft tissue pull on the osteotomy and adjacent bony structures can be modulated. Tension forces have been shown to induce histogenesis, a secondary beneficial effect to create new soft tissue as well as bone.^{4,5}

Because orthognathic surgery using DO does involve the slow movement of the bone segment over time, careful patient selection is advocated. Patients with poor compliance or high expectations and needs may not be the ideal candidates for the distraction technique. However, patients “at risk” for surgical relapse or secondary problems at the level of the TMJ from excessive soft tissue load are ideal candidates for sagittal advancement of the mandible using DO.

Condylar position and proximal segment control for bilateral sagittal split osteotomies (BSSO) have been the topic of numerous lectures and publications. Positioning devices and technique modifications have been advocated, as torquing of the condyle has been reported postoperatively after BSSO surgery.^{6,7} The advent of rigid fixation has enhanced the technique of orthognathic surgery. Both the bicortical screw and plate fixation techniques for BSSO surgery can lead to significant condylar axis changes postoperatively. Improper orientation of the sagittal osteotomy overlap, or bone segment compression during the application of rigid fixation, is translated to condylar repositioning within the fossa.^{8,9} Over the long term, both adaptive bony changes as well as degenerative changes can occur, depending on the amount of condylar axis change and the patient’s predisposition to derangement of the TMJ. It has been reported that patients with preexisting TMJ disorders, undergoing mandibular advancement using conventional

orthognathic techniques, can expect to have a worsening of symptoms postoperatively.¹⁰

Distraction osteogenesis has been shown to provide a partial solution for the protection of condylar function by gradual vectored distraction following orthognathic principles.^{11,12} Comparison of radiographic submental vertex views of the mandible, taken before and after sagittal mandibular advancement of the mandible using DO, has shown preservation of the condylar axis (Figure 30-1). An intraoral distractor using the microplate design addresses both the esthetic concerns of patients and the clinician’s concerns of ease of device placement (Figure 30-2). The device activation port is located in the buccal sulcus, which facilitates easy device activation with minimal intraoral visibility (Figure 30-3). The advent of the microplate design has facilitated device placement, significantly decreasing the intraoperative time. The mesh footplates are placed directly on the bone, with the arm extending from the bone to the distractor, which

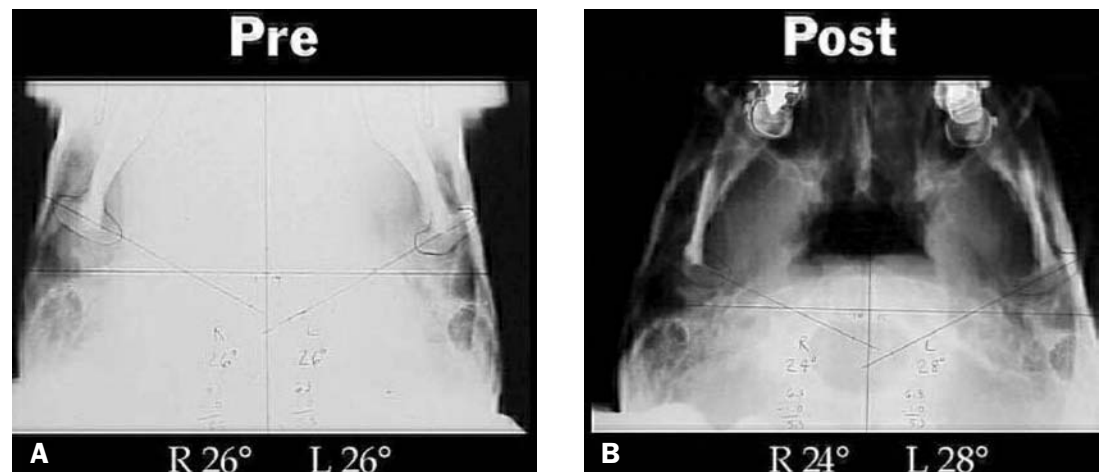


FIGURE 30-1 A, Preoperative submental vertex (SMV) radiograph before sagittal distraction osteogenesis (DO) surgery B, Postoperative SMV radiograph after sagittal DO of the mandible, showing condylar axis preservation.

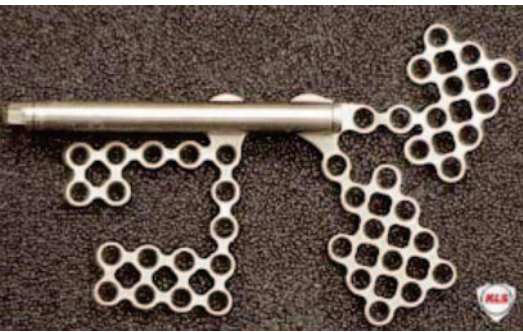


FIGURE 30-2 Moses/Stucki intraoral sagittal distractor with mesh footplates. Reproduced with permission of KLS Martin, L. P, Jacksonville, FL.

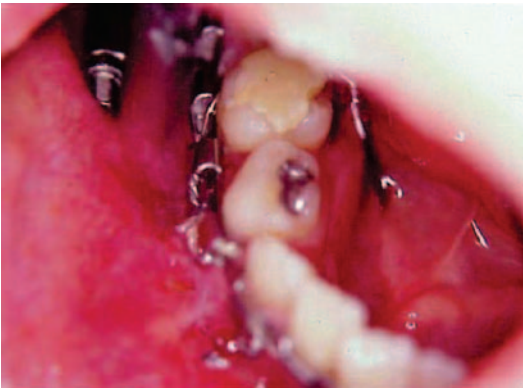


FIGURE 30-3 Sagittal distractor in a patient, showing the activation screw in the buccal sulcus next to the molars.

is extraosseous in location (Figure 30-4). The screws are placed in a monocortical fashion, protecting erupted teeth, tooth buds, and the inferior alveolar nerve.

The distractor is positioned in the buccal sulcus so that it is located away from the osteotomy site, preventing local wound and bone healing problems. The distractor sits in an intraoral and extramucosal position in the buccal vestibule,

such that direct visualization of device activation can be performed and verified. During active DO, the arms of the footplate can be judiciously bent to allow for small device trajectory changes and callus manipulation. This is in contrast to the current technique of callus manipulation, which requires distraction device removal prematurely, prior to ossification.¹³ The distraction device is easily removed, as only the footplates are submerged below the mucosa. The distraction device is oriented along the midsagittal plane, parallel to the occlusion, taking into account the convergence of the lateral mandible (Figure 30-5).¹⁴⁻¹⁶ Placing the distractor extraosseous in the buccal vestibule takes advantage of the potential space of the buccal vestibule, such that the distractor can be easily placed parallel to the midsagittal plane. A submerged device would not allow for this device orientation, as closure of the wound

may limit device parallelism. Properly vectored distraction appears to minimize condylar torque.

Surgical Technique

The surgical technique involves the use of an intraoral distraction device (KLS Martin, Jacksonville, FL) and modification of the bilateral sagittal split ramus osteotomy. The incision is made on the lateral aspect of the ramus overlying the external oblique ridge. The incision is carried to the first molar area along the approximate line of the distraction plate position to avoid bunching of the tissue during closure and to allow ease of device removal (Figure 30-6). Soft tissue subperiosteal dissection exposes the ramus. The planned site of the sagittal osteotomy is verified and the vertical buccal cut scribed or marked. The distraction device is then bent to lie passive on the

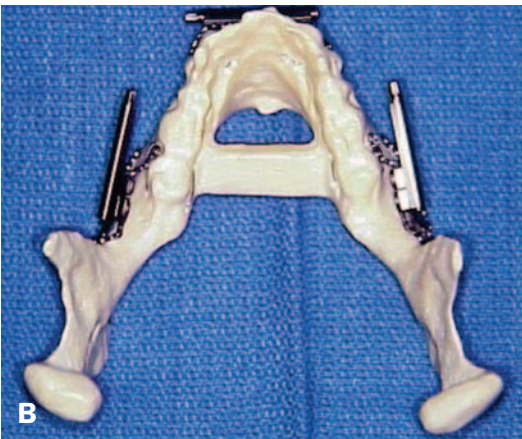
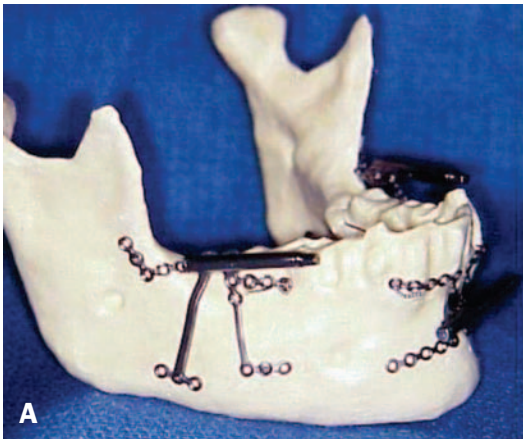


FIGURE 30-5 A, Bilateral sagittal distractor placement with the demonstrated orientation plane along the occlusal plane and footplate positions. B, Bilateral sagittal distractor placement demonstrating positioning parallel to the midsagittal plane. Note that the anterior-superior footplate is stepped and wire ligated to the molar to allow this vector orientation.

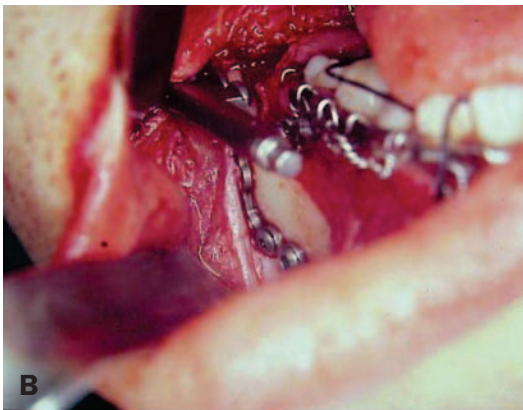


FIGURE 30-4 A, A sagittal distractor activation tube, shown placed extramucosally. B, Sagittal distractor mesh footplates trimmed and arms contoured to bone.

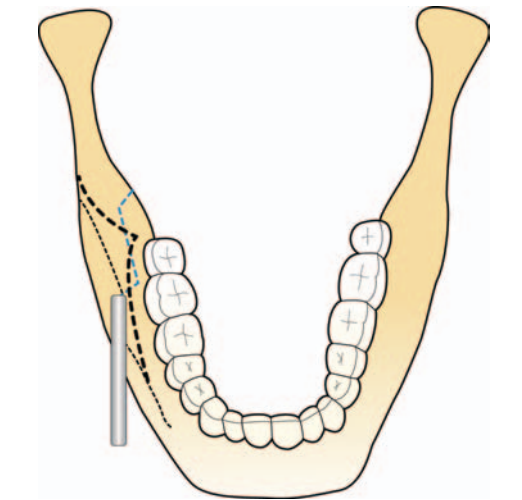


FIGURE 30-6 Drawing of the sagittal incision for best device footplate coverage and minimal soft tissue stripping.

bone as well as to incorporate the planned vector of distraction (Figure 30-7). The vertical limbs of the distraction device footplates are first bent in a lateral step fashion to ensure proper device trajectory. The mesh footplates are easily adapted to the bone using a periosteal elevator. The anterior–superior-most footplate is bent in a step fashion, adapted to the posterior mandibular teeth, and ligated incompletely with 24-gauge wire to a posterior molar, anterior to the osteotomy split. The remaining three mesh footplates are reduced in size to allow for ease of device placement with a minimum of three screws

(2.0 mm) in each of the footplates (Figure 30-8). Device position and trajectory are verified against the planned osteotomy. The device is secured to the mandible with 2.0-mm-diameter, 4.0- to 5.0-mm-length self-tapping monocortical screws via the percutaneous approach. Only one screw per footplate is initially placed. The circumferential wire of the anterior–superior footplate is then completely tightened and the remaining screw sites drilled, but the screws are not placed (Figure 30-9). The screws, wire, and device are then removed to allow for completion of the modified sagittal osteotomy.

The BSSO is modified to shorten the oblique sagittal bone cut (Figure 30-10). Since new bone is being generated during the distraction process, the amount of bony overlap of the proximal and distal segments can be minimized. Additionally, the rate of distraction is increased to 2.0 mm advancement per day, preventing premature ossification of the distraction gap, which is especially important in the pediatric population. The BSSO is also modified to be both shorter with less overlap and to include the creation of a groove in the lingual cortex at the site of the horizontal bone cut. The soft tissues and neurovascular bundle are



FIGURE 30-7 Occlusal view of sagittal distractor placed on the mandibular distraction site illustrating the stepped - banding of the two superior plates allowing proper vector alignment of the distraction to be.

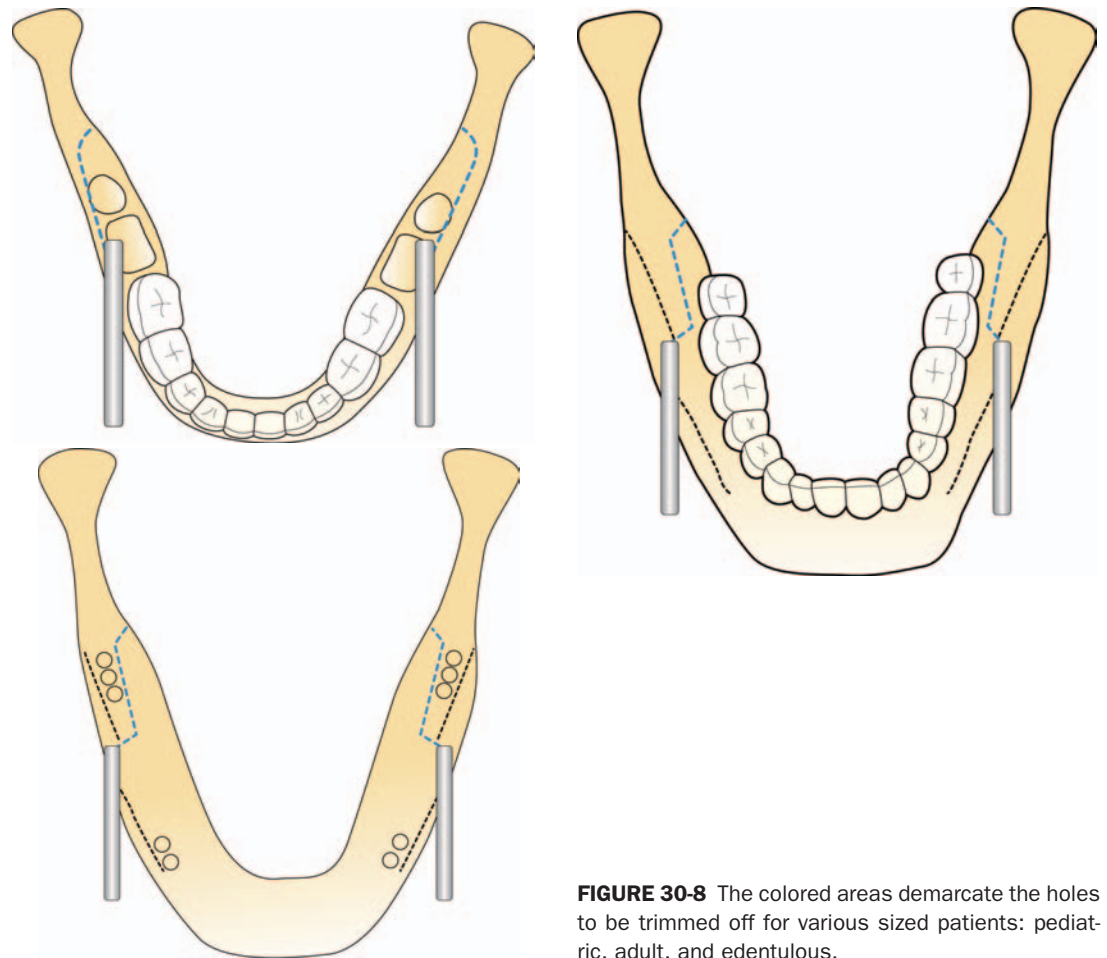


FIGURE 30-8 The colored areas demarcate the holes to be trimmed off for various sized patients: pediatric, adult, and edentulous.

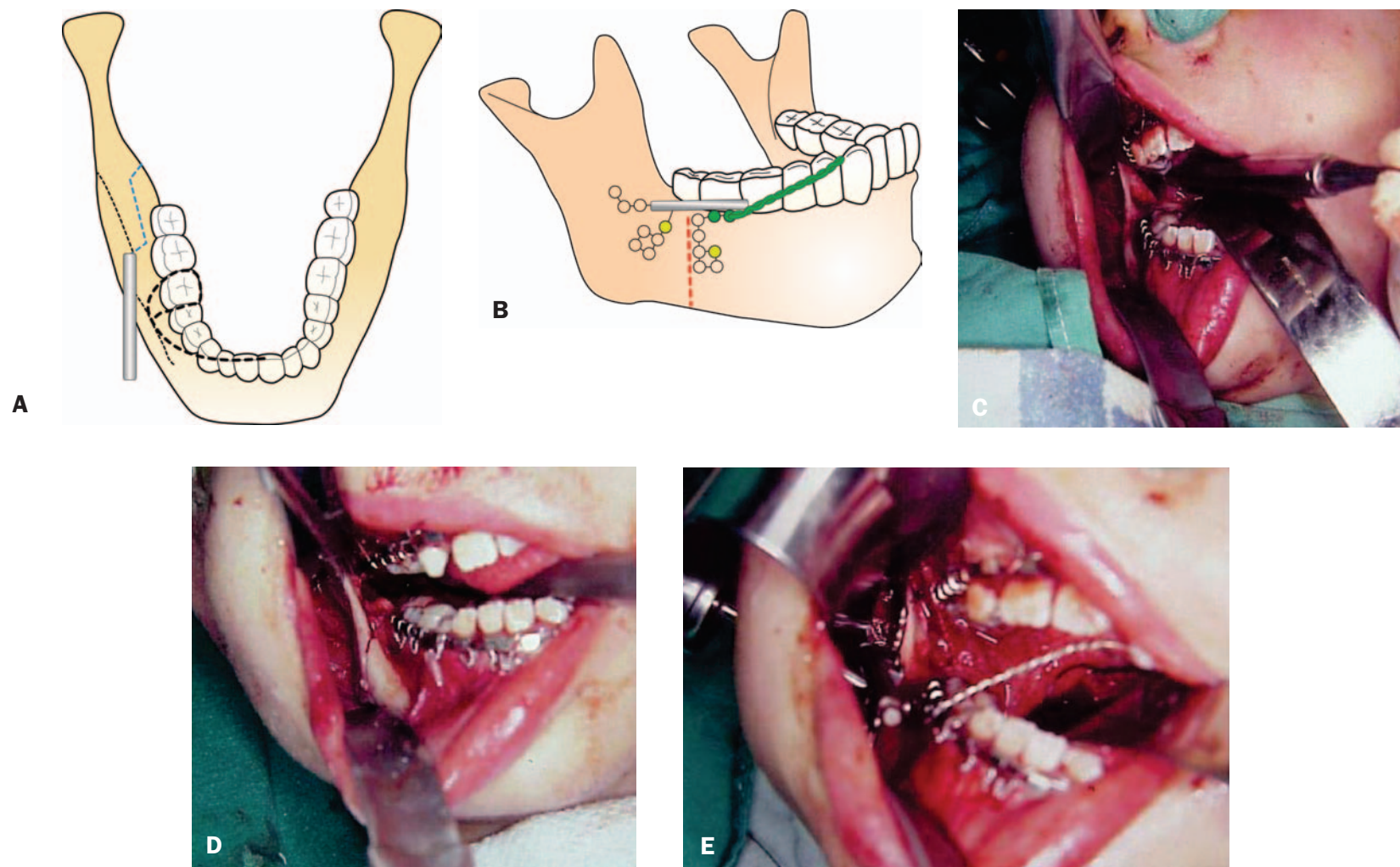


FIGURE 30-9 A, Drawing of the plate on the mandible with wire on the anterior–superior footplate ligating it to the molar. B, Drawing of the plate on the mandible already ligated to the molar, with one hole marked in color filled with a screw in each of the other three footplates. C, Sagittal soft tissue incision and exposure. D, Positioned distractor with bending of the footplates. E, Distractor with wire on the anterior–superior footplate affixing it to the molar.

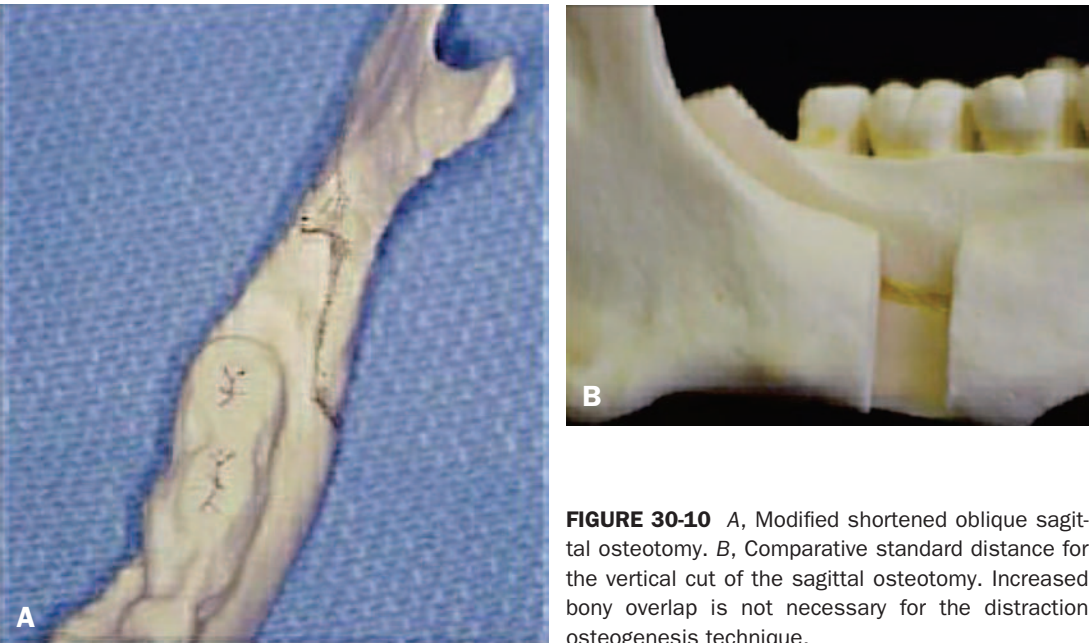


FIGURE 30-10 A, Modified shortened oblique sagittal osteotomy. B, Comparative standard distance for the vertical cut of the sagittal osteotomy. Increased bony overlap is not necessary for the distraction osteogenesis technique.

protected, and a large round bur is used to create a trough at the site of the horizontal osteotomy (Figure 30-11). This modification ensures minimal bony interferences between the proximal and distal segments, which allows for impedance-free movement of the distal segment during callus manipulation. A reciprocating saw is used to complete the sagittal osteotomy. Osteotomy cuts are created on the contralateral side in a similar fashion. The bone segments are then separated, with assurance that the inferior alveolar nerve is released from any restrictions on the proximal segment. Additionally, no release of the medial pterygoid muscle is advocated in order to maximize the vascularity to the proximal segment. A gauze pack is then placed, and the same surgical procedure is performed on the contralateral side.

The distraction device is then reapplied. The distraction device is initially secured to the proximal segment by ligating the anterior–superior footplate loosely to the selected mandibular molar

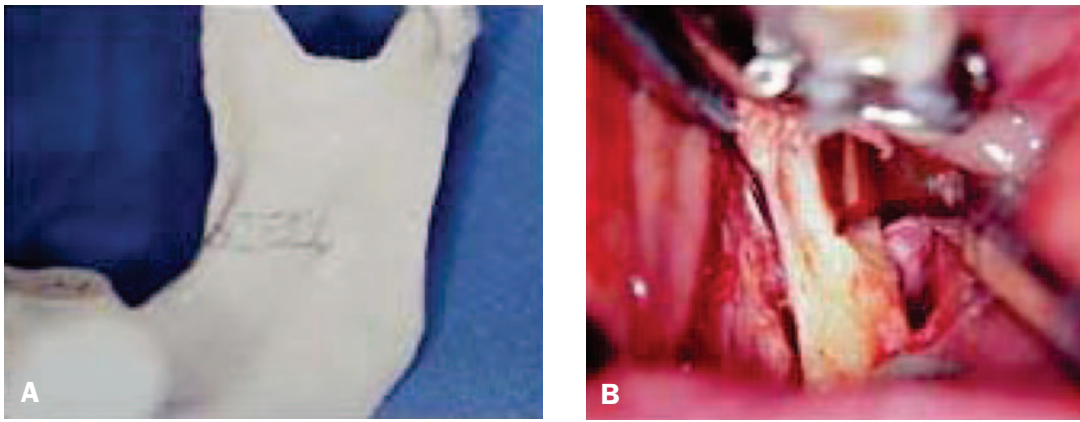


FIGURE 30-11 A, Mandibular medial ramus surface, shown with the marked area of bony removal. B, Vertical and horizontal ramus osteotomy, made in order to reduce interferences that may occur during callus manipulation during distraction osteogenesis to finalize the position of the distal mandible.

with 22-gauge wire. The remaining footplates are then secured with monocortical screws in the same predrilled pattern, and the 22-gauge wire is then tightened completely. The device trajectory and segment movement are verified by activating the distraction device. The device application is then performed in a similar fashion on the first side. Both devices are activated to verify impedance-free movement of the segments. The device is closed, returning the segments to their original position (Figure 30-12). The wound is closed in layers.

Surgical Considerations

The basic Ilizarov principles are followed: 5-day latency, daily distraction, consolidation, followed by device removal (Figure 30-13).¹⁷ The distraction rate is modified and increased to 2.0 mm per day (1.0 mm twice-daily advancement) to accommodate the increased bony contact from the modified BSSO, thereby preventing premature osseous consolidation. Should patients experience discomfort during device activation, the rhythm of distraction can be modified to 0.5 mm

advancement four times daily, achieving the total daily distraction of 2.0 mm.

For patients with asymmetric mandibular movements, “callus dancing” is performed.¹¹ Here, both sides of the mandible are activated in the morning, advancing the mandible 1.0 mm. In the evening, the shorter (“dancing”) side is once again distracted 1.0 mm, and the longer (“waiting”) side is contracted 1.0 mm. This dancing technique proceeds until both sides of the mandible achieve equivalence in anteroposterior (A-P) dimension. Then, bilateral distraction continues, using the 1.0 mm twice-daily protocol, until the final mandibular position is achieved.

Interoperatively, a maxillary splint is ligated to the upper teeth to help guide the mandible to the planned occlusion. The mandible is advanced to the planned position, as verified by the occlusion “locking into” the splint. The distraction protocol is stopped, and the consolidation phase initiated. The maxillary splint is removed 1 week after the initiation of the consolidation phase. Callus manipulation can be performed once the surgical splint has been removed.

During active mandibular advancement by distraction, 6 oz Class II orthodontic elastics are applied bilaterally to unload the TMJ. This is maintained as long as the maxillary splint is in place. During the next 3 to 6 weeks of the consolidation phase, and after maxillary splint removal, the elastics are then applied in a neutral pattern. During the day, the elastics are placed to allow for limited mandibular movement, and at night, the elastics are placed to achieve maxillomandibular fixation. This allows for final interdigitation of the teeth and settling regeneration using callus manipulation. During the final 3 to 6 weeks of consolidation, the elastic pattern is according to the orthodontist’s preference.

During active DO and consolidation, patients maintain a soft, non-chew diet. Additionally, the elastics are removed every hour to allow the patient active mobility with home physical therapy following the Rule of Tens: 10 repetitive motions of opening, right lateral excursion, left lateral excursion, and protrusion, 10 times a day. The elastics are also removed for eating and oral hygiene. At home, exercises can be supplemented with physical therapy modalities, should patients experience myofascial pain. Passive mobilization via device- or hand-assisted movements of the mandible during physical therapy is not advocated.

The distraction device is removed after 8 to 12 weeks of consolidation. Healing of the segments is verified using the same clinical parameters as for orthognathic surgery, including palpable stability of the segments and evidence of a cortical outline on radiography (Figure 30-14). Removal of the device is easy, as only the footplates are submerged. The incision is modified, for the scalpel blade follows the path of the

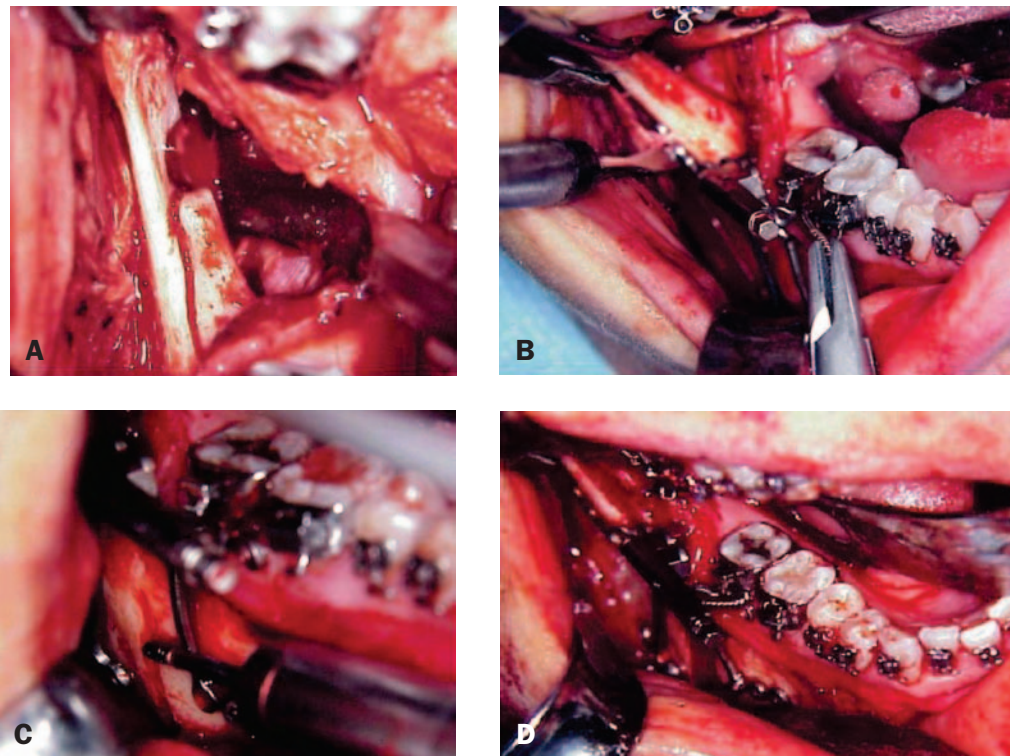


FIGURE 30-12 Sequence of the procedure. A, Medial and superior osteotomy/osteotomy B, Loose wiring of the anterior-superior footplate to the molar. C, Scoring of the vertical osteotomy. D, Placement of a single screw in each of the remaining three footplates to stabilize while pre-drilling the remaining holes.

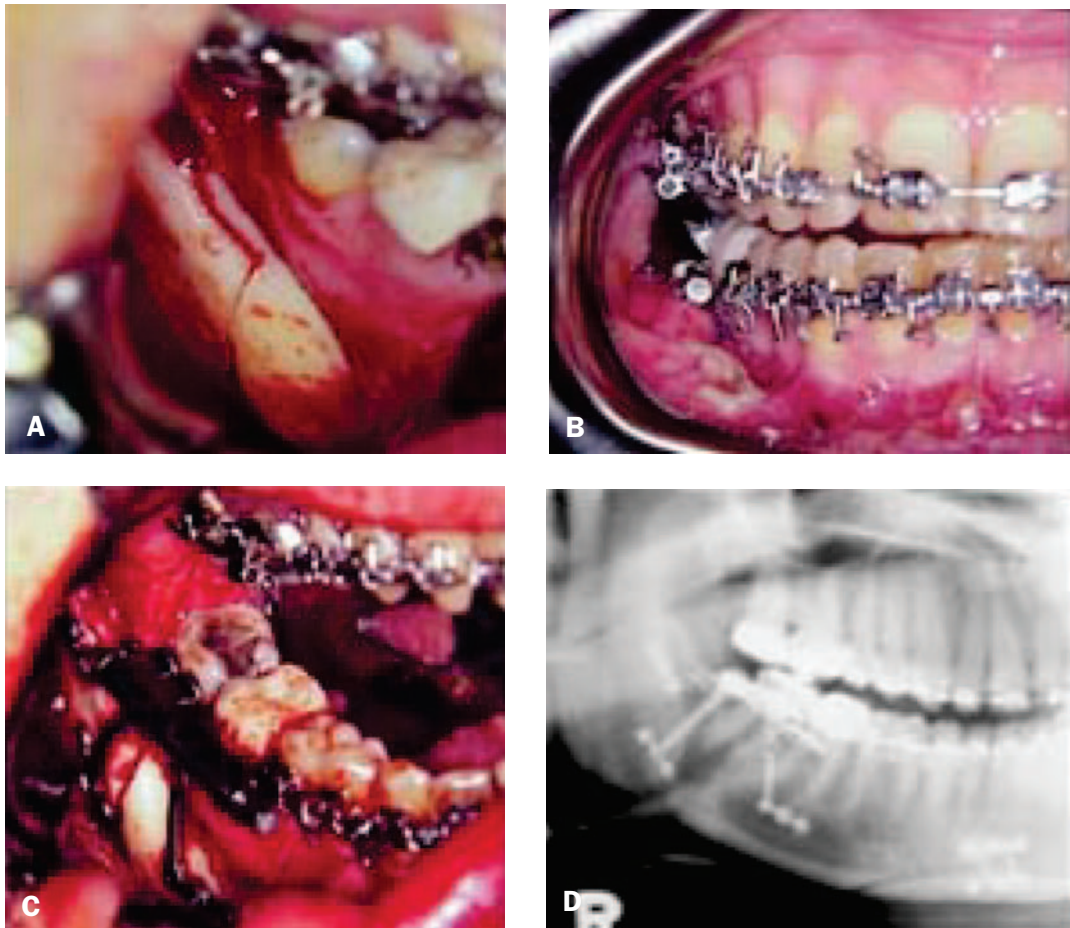


FIGURE 30-13 Steps of procedure continued. A, Removal of the device and completion of the osteotomy. B, Device placement and vector orientation along the occlusal and midsagittal plane confirmed. C, Device opened and closed, checking for interferences. D, Immediate postoperative radiograph.

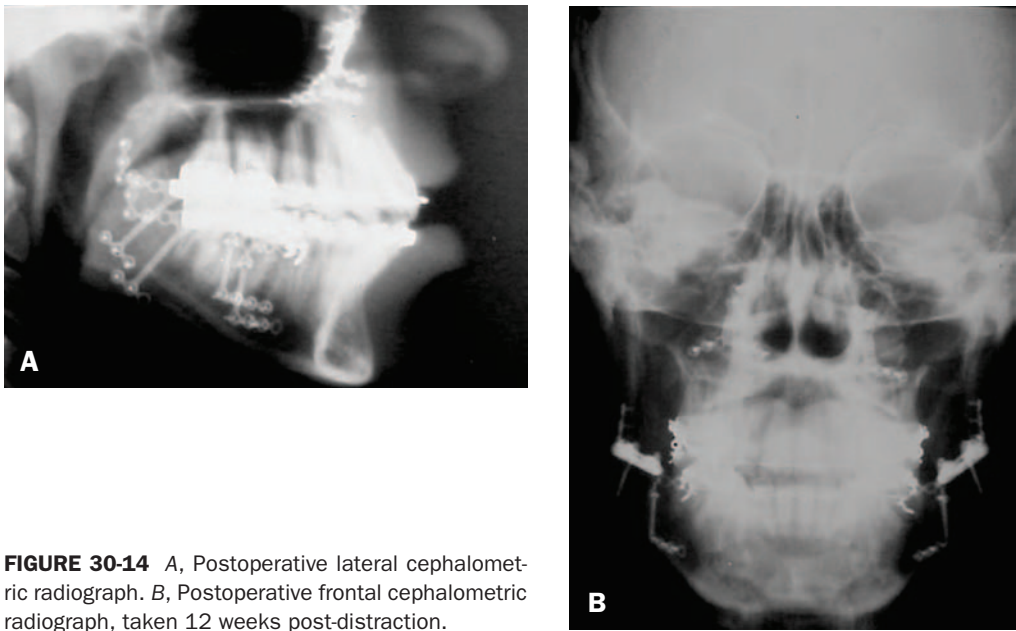


FIGURE 30-14 A, Postoperative lateral cephalometric radiograph. B, Postoperative frontal cephalometric radiograph, taken 12 weeks post-distraction.

footplate to readily expose the screws, rather than making a vestibular incision. Should incomplete ossification be observed, the patient is placed in maxillomandibular fixation and a monocortical miniplate is placed. Occasionally, the distraction device is removed early, either at the patient's request or if there is poor compliance with maintenance and hygiene. In these cases, a resorbable mesh is ideal for segment or callus stabilization (Figure 30-15).

Postsurgically, patients are evaluated weekly for the first month, monthly for the first 6 months, and then yearly. Evaluation includes physical examination; tactile neurosensory testing; and radiography of the panoramic and cephalometric views as well as tomographic evaluation of the TMJ, including a submental vertex view, obtained at the immediate postoperative appointment, at the end of distraction, at the end of consolidation, and at 6 months and yearly thereafter.¹⁸

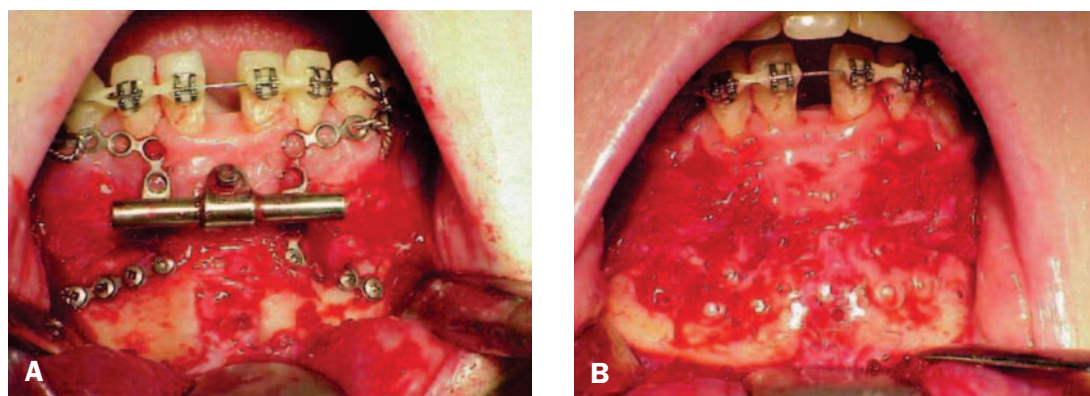


FIGURE 30-15 A, Example of early device removal due to lip irritation. B, Resorbable mesh used for callus stabilization.

Patient Selection

Mandibular Advancement

Significant mandibular advancement (7.0 mm or greater) has been shown to have an increased rate of surgical relapse.^{2,3} Soft tissue strain and excessive muscle pull have been implicated as the primary causative factors for this relapse. The relapse can be manifested as a loss of advancement length along the body of the mandible, or at the level of the mandibular condyle, creating an open bite. For patients with significant mandibular advancement surgery, DO is a good clinical alternative. The slow application of force over time allows for passive stretch of the muscles. Daily mandibular advancement using DO allows the muscles to “adapt” to the new position daily, rather than an immediate reposition and fixation. Additionally, the stretching of the underlying collagen fibers has been implicated in inducing metaplasia and histogenesis.^{4,5}

Preexisting Temporomandibular Joint Conditions

Patients with preexisting TMJ disorders requiring orthognathic surgery pose a clinical challenge: will treating the mandibular hypoplasia exacerbate their existing TMJ disorder? For

patients with open bite deformities secondary to degenerative joint disease, complete avoidance of mandibular surgery has been advocated, correcting the malocclusion through maxillary surgery instead and thereby reducing the chance of aggravating the condylar condition.¹⁹ Patients with mandibular hypoplasia and high mandibular plane angles have been shown to have an increased risk of idiopathic condylar resorption after BSSO.^{20,21} Conversely, DO has been shown to have beneficial effects at the level of the mandibular condyle.²²

Generally, patients with mandibular hypoplasia and TMJ disorders should be treated in a sequential approach. Phase I: normalize the TMJ condition; followed by Phase II: mandibular advancement surgery using DO. Phase I treatment encompasses nonsurgical therapy including splint therapy, physical therapy, and arthroscopic surgery if indicated. If presurgical orthodontic therapy has been completed, patients who have responded well to Phase I therapy can proceed to Phase II, 1 month after completion of the Phase I treatment: maximal interincisal opening > 40.0 mm, right lateral excursive motion > 7.0 to 10.0 mm, left lateral excursive motion > 7.0 to 10.0 mm, protrusive excursion of > 7.0 to 10.0 mm.²³

Mandibular Asymmetry

Maintenance of the condylar position for asymmetric mandibular advancement is difficult to achieve using rigid fixation. To correct the midline, the mandible is shifted as it is advanced away from the affected side. This results in a larger gap at the proximal end of the distal segment. Placement of rigid fixation screws often results in the narrowing of this gap, thereby torquing the mandibular condyle.⁸ For patients with preexisting TMJ disorders, this torquing phenomenon may be outside the adaptive capabilities of their condyle, which may result in the exacerbation of their clinical condition. Here, sagittal mandibular advancement using DO is a good treatment alternative. The preoperative treatment is the same as conventional orthognathic surgery, with orthodontic leveling and aligning of the teeth of the maxillary and mandibular arches. Rather than immediate BSSO advancement, the mandible is gradually sagittally distracted to the proper position.

As described above, the distraction protocol is modified to correct for the asymmetry. Initially, the lesser, “dancing” side is advanced differentially, by activating both distractors 1.0 mm in the morning. In the evening, the shorter, “dancing” side is once again distracted 1.0 mm, and the longer, “waiting” side is contracted 1.0 mm. This dancing technique proceeds until the asymmetric side matches the contralateral side in the A-P dimension. Then, bilateral distraction continues using the 1.0 mm twice-daily protocol until the final mandibular position is achieved. Interestingly, as noted on the submental–vertex radiographs, the condylar axis will change slightly to account for the correction of the mandibular asymmetry. We have, thus far, seen no effect on the patients’ clinical outcome, as these patients have remained asymptomatic regarding TMJ complaints.

Case Example

This case exhibits a combination of three indications for DO: a large mandibular A-P hypoplasia, temporomandibular joint dysfunction (TMD), and skeletal mandibular asymmetry (Figures 30-16A through 30-16Z).



FIGURE 30-16 A, Frontal photo of a patient with asymmetric mandibular anteroposterior hypoplasia and asymmetric symphysis. B, Pre-distraction panoramic radiograph. C, Side view of occlusion, showing severe anteroposterior discrepancy with 22 mm mandibular hypoplasia. D, Lateral photograph, showing mandibular deficiency. E, Lateral cephalometric radiograph, showing anteroposterior hypoplasia. F through I, Sagittal temporomandibular joint tomograms taken in closed occlusion position, showing degenerative joint disease preoperatively with no change postoperatively at 6 months. The preoperative right lateral tomogram (F), postoperative right lateral tomogram (G), preoperative left lateral tomogram (H), and postoperative left lateral tomogram (I) are shown. J through M, Coronal temporomandibular joint tomograms taken in the protruded jaw position with teeth edge to edge. The preoperative right tomogram (J), postoperative right tomogram (K), preoperative left tomogram (L), and postoperative left tomogram (M) are shown.



FIGURE 30-16 continued. *N*, Preoperative front face. *O*, Preoperative side face. *P*, Postoperative front face. *Q*, Postoperative side face. *R*, Postoperative open mouth view with functioning temporomandibular joints. *S*, Preoperative lateral cephalometric radiograph. *T*, Postoperative lateral cephalometric radiograph after 12 weeks of consolidation and device removal. *U*, Preoperative frontal radiograph. *V*, Postoperative frontal radiograph.

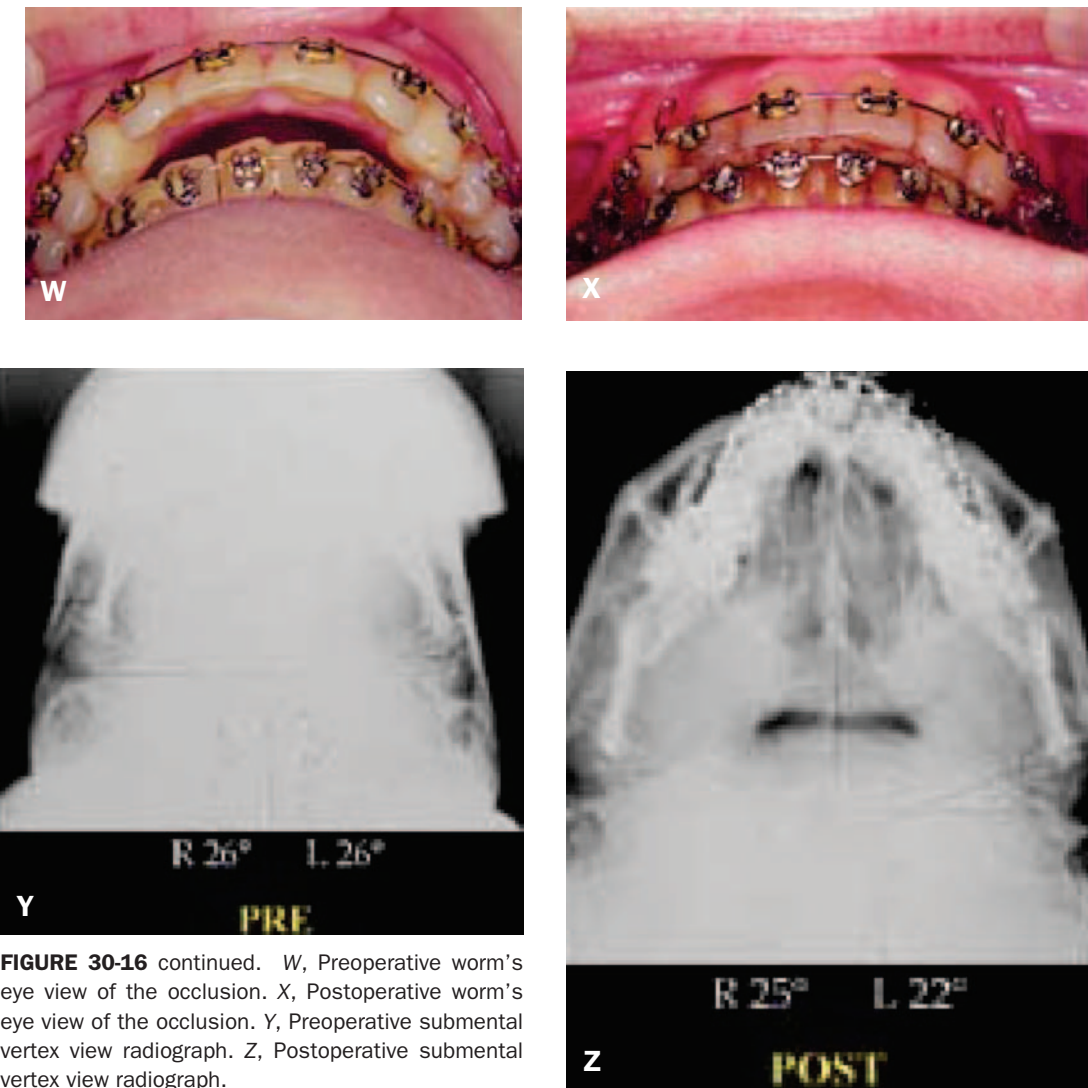


FIGURE 30-16 continued. W, Preoperative worm's eye view of the occlusion. X, Postoperative worm's eye view of the occlusion. Y, Preoperative submental vertex view radiograph. Z, Postoperative submental vertex view radiograph.

A 38-year-old woman presented with a 22 mm asymmetric skeletal mandibular deficiency, painful TMD with limited mouth movements and opening, internal disc derangements, and degenerative joint disease. Presurgical orthodontic therapy was completed, as well as non-surgical TMJ therapy. This patient had continued TMD despite the nonsurgical therapy and thus had bilateral surgical TMJ arthroscopy, which stabilized her joint dysfunction several months prior to the skeletal surgery. Owing to the TMD as well as the large and asymmetric sagittal mandibular advancement required, DO was used. Callus dancing was used, as both the mandible and the symphysis were asymmetric. Because this patient had a deep curve of Spee, the open bite between the bicuspsids and second molar was corrected when the prosthodontist replaced the existing bridge. Postoperative neurosensory testing revealed a faster return of lip sensation than that predicted for mandibular advancement using conventional sagittal split osteotomies for her age group (Table 30-1).^{12,22}

Table 30-1 Nerve Function				
Week	2	4	6	12
Side:right/left	R/L	R/L	R/L	R/L
Sense chin	P/P	P/P	P/P	N/N
Sense lip	P/P	P/P	N/N	N/N
Chin 2 point	--	--	--	--
Lip 2 point	--	--	++	++
Chin direction	+-	+-	++	++
Lip direction	+-	+-	++	++

Patients Considered “At Risk” for Condylar Resorption.

Mandibular advancement in the best of circumstances can lead to skeletal relapse. The relapse often occurs at the level of the mandibular condyle and can result in progressive idiopathic condylar resorption, resulting in a Class II profile and open bite. Large case study reviews have identified nonsurgical risk factors associated with

idiopathic condylar resorption. Patients considered “at risk” include those with posterior inclination of the condylar neck and high mandibular plane angles (Figure 30-17).^{19,20} These patients are ideal candidates for sagittal advancement of the mandible using DO. Here, the mandibular advancement is slow and progressive. The distraction sequence can also be modified to allow for the 2.0 mm advancement per day to be divided into smaller incremental daily advancements (ie, 0.5 mm four times daily, rather than 1.0 mm twice daily), thus allowing a sequential stretching response to the bone advancement.

Concomitant Maxillary and Mandibular Surgery

Distraction osteogenesis can be easily combined with conventional maxillary orthognathic surgery, especially for patients with preexisting TMJ disorders. The maxilla is approached surgically with the classic Le Fort osteotomy technique. Using an interim surgical splint, the maxilla is rigidly fixated to place. Lindorf plates located at the piriform rim are ideally suited for rigid fixation of the maxilla in patents with preexisting TMJ conditions.

The mandible is then advanced using the sagittal distraction technique. The surgery proceeds as described. As with all patients, a surgical splint is ligated to the maxillary teeth, to guide the mandible to its final position. This is removed 1 week after the termination of active distraction. For patients undergoing segmental maxillary osteotomies, the maxillary splint is not removed at the end of active distraction. Rather, the splint is held in place for 6 weeks, until the orthodontist can place the continuous-arch and cross-arch stabilization wires. Usually, the patient appointments are coordinated such that the splint removal and the wire application occur within 24 hours of each other.

Case Example

This case has several indications for the use of DO, including TMD with mandibular hypoplasia in addition to needing concurrent Le Fort maxillary surgery (Figures 30-18A through 30-18BB).

A 22-year-old female presented for evaluation of her dentofacial deformity and TMJ condition. Her findings included painful limited mouth opening, bilateral internal derangement of the TMJ (nonreducing, anteriorly dislocated discs), vertical maxillary excess, moderate A-P discrepancy of the maxilla and mandible for mandibular hypoplasia of 8.0 mm, and radiographic evidence of degenerative joint disease including beaking of the mandibular condyles with decreased joint space and subcondylar sclerosis. Phase I therapy was performed including presurgical orthodontics and nonsurgical TMD

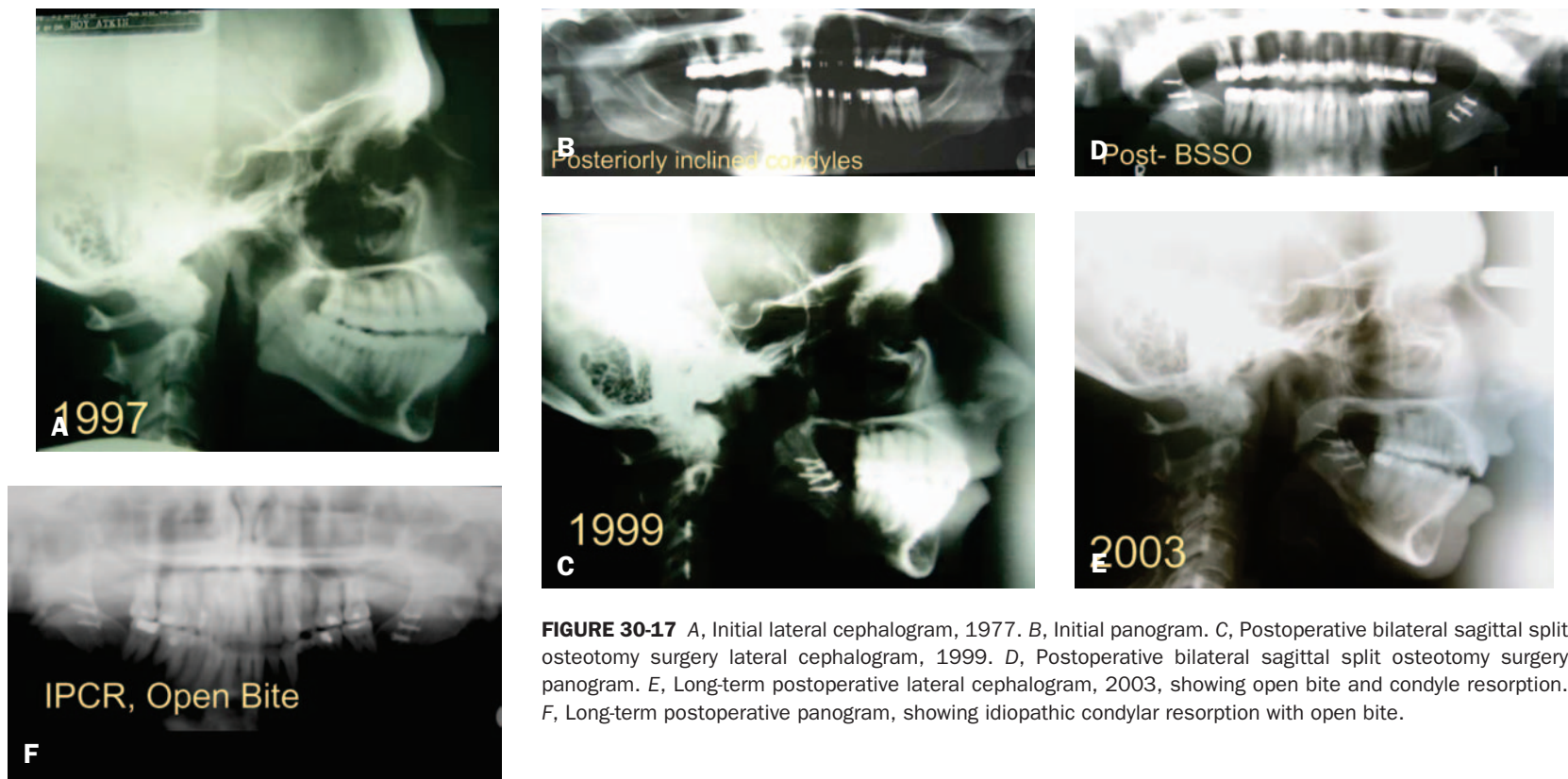
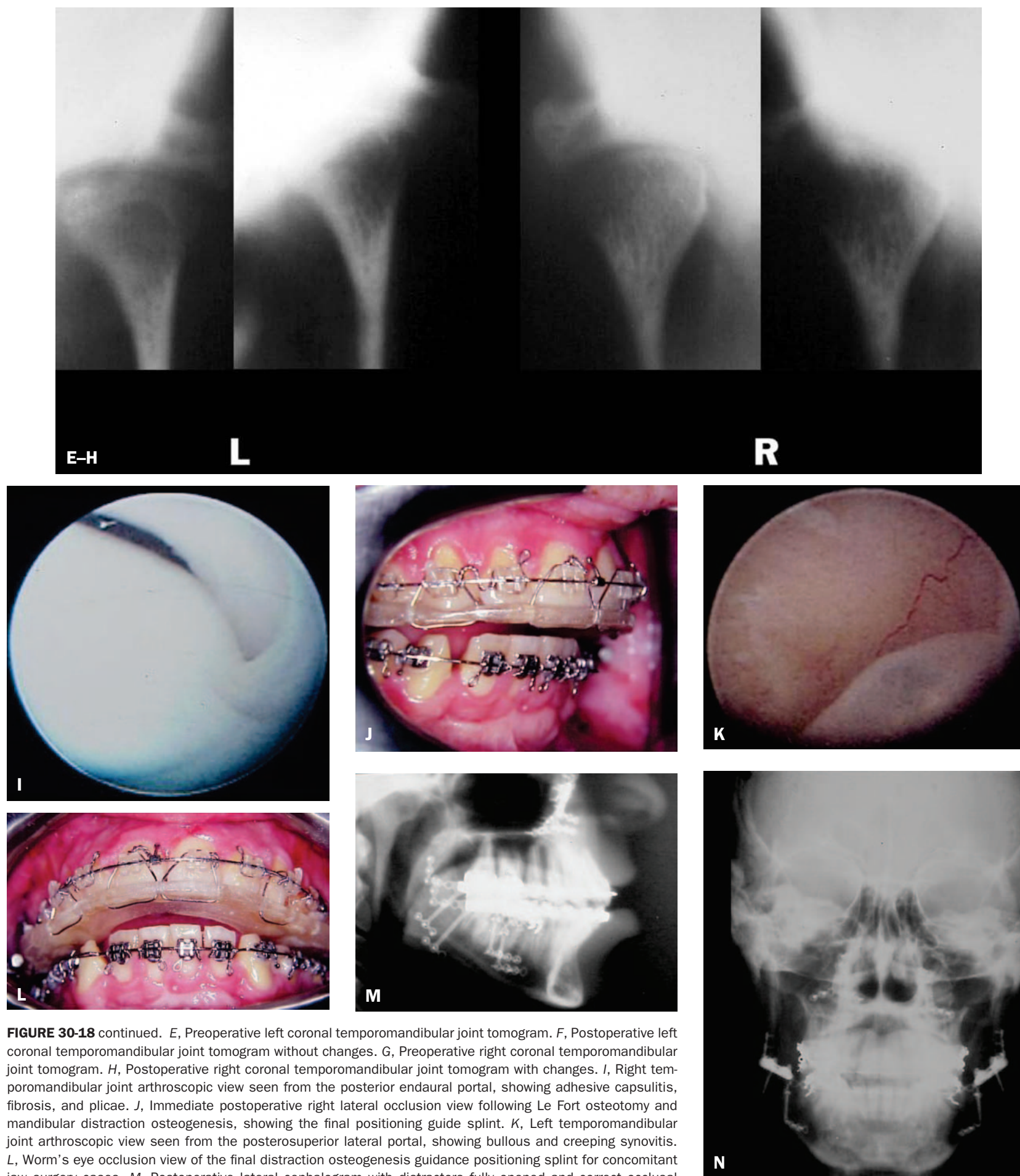


FIGURE 30-17 A, Initial lateral cephalogram, 1977. B, Initial panoramic. C, Postoperative bilateral sagittal split osteotomy surgery lateral cephalogram, 1999. D, Postoperative bilateral sagittal split osteotomy surgery panoramic. E, Long-term postoperative lateral cephalogram, 2003, showing open bite and condyle resorption. F, Long-term postoperative panoramic, showing idiopathic condylar resorption with open bite.



FIGURE 30-18 A, Frontal photograph, showing limited and deviated mouth opening to the left. B, Lateral photograph, showing mandibular deficiency. C, Frontal cephalogram, showing hypertrophic turbinate and septal spurs with deviation leading to obstructive nasal respiration. D, Lateral cephalogram, showing mandibular anteroposterior hypoplasia and vertical maxillary excess.



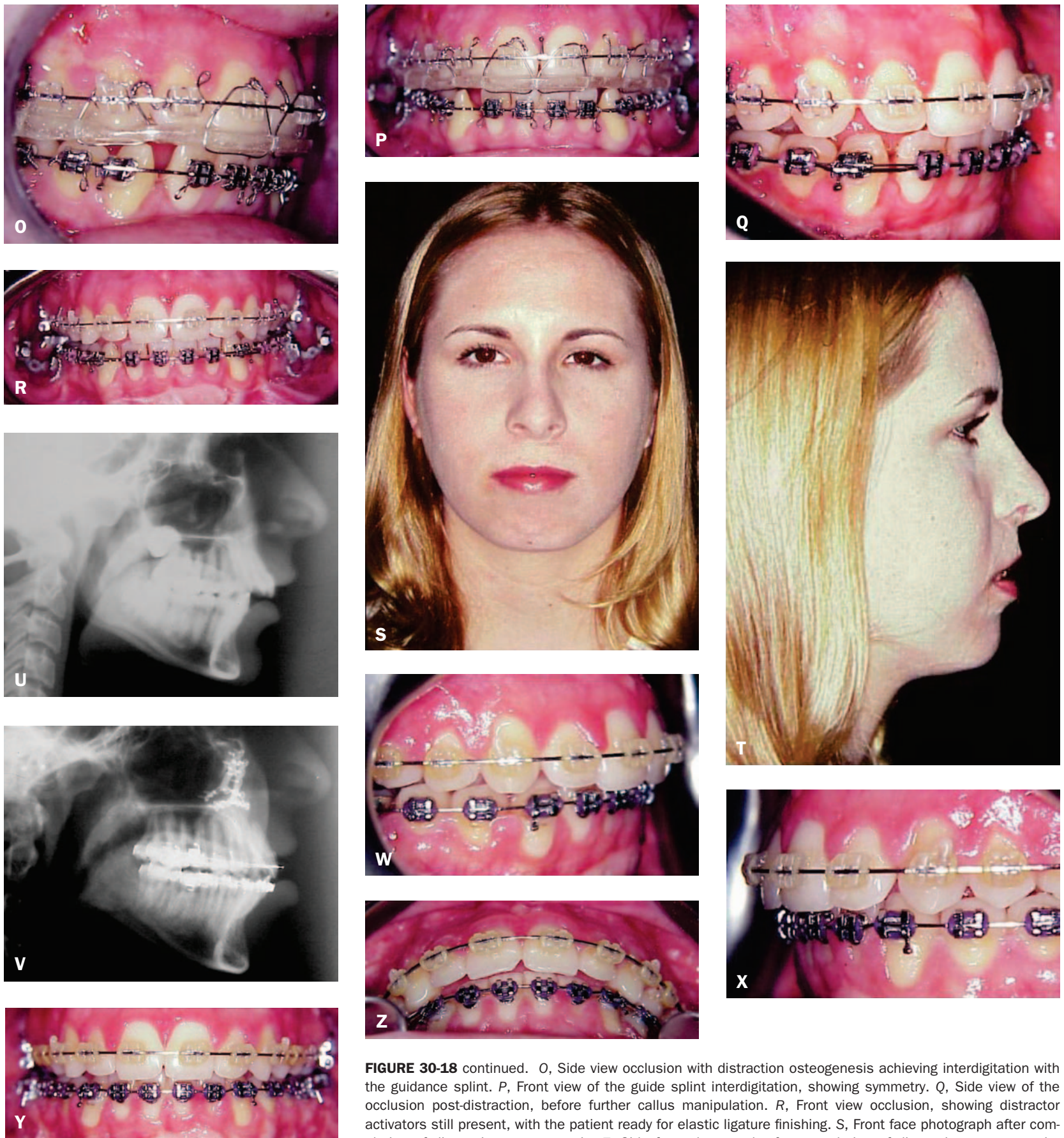


FIGURE 30-18 continued. O, Side view occlusion with distraction osteogenesis achieving interdigitation with the guidance splint. P, Front view of the guide splint interdigitation, showing symmetry. Q, Side view of the occlusion post-distraction, before further callus manipulation. R, Front view occlusion, showing distractor activators still present, with the patient ready for elastic ligature finishing. S, Front face photograph after completion of distraction osteogenesis. T, Side face photograph after completion of distraction osteogenesis. U, Preoperative lateral cephalogram. V, Consolidation postoperative lateral cephalogram, showing the device removed and the final skeletal position. W, Right side view postoperative occlusion. X, Left side view postoperative occlusion. Y, Front view postoperative occlusion. Z, Worm's eye view postoperative occlusion.



FIGURE 30-18 continued. AA, Preoperative submental vertex view with the condyle axis right 26° and left 22°. BB, Postoperative submental vertex view with the condylar axis preserved with right 26° and left 24°.

therapy, followed by arthroscopic surgery. Findings at surgery included the following: Right side: adhesive capsulitis, with fibrosis and plicae; Left side: bullous synovitis and creeping synovitis. Phase II therapy included 2-piece maxillary impaction with rigid fixation and mandibular advancement using DO. Here, the patient was treated as planned until an edge-to-edge occlusion was achieved, allowing for final callus manipulation using orthodontic elastics.

Mandibular Advancement with Ramal Elongation for Patients with Craniofacial Microsomia

Distraction osteogenesis found its origins in the treatment of mandibular deformities for patients with craniofacial microsomia.^{4,5} As the distraction technique became more streamlined, the use of intraoral distraction devices was advocated. Additionally, concerns about the inferior alveolar nerve and tooth buds became a more pressing issue.²⁵ Use of the sagittal distraction technique addresses these concerns. The microplate design of the distractor requires only monocortical screws, avoiding damage to erupting teeth. The sagittal nature of the osteotomy acts to protect the inferior alveolar nerve. As the bone cut is sagittal, during active distraction, the nerve remains surrounded by either the buccal or lingual plate of the osteotomy. This is in contrast to a circumferential osteotomy of the mandible, whereby the segments are separated and the bone gap filled only with the fibrous matrix, which eventually ossifies to produce osseous continuity (see Figures 30-10A and 30-10B).

As most patients with craniofacial microsomia have concomitant maxillary deformities, these can be corrected with DO using orthodontic elastic forces at the same surgical setting. Here, the maxilla is approached as for conventional orthognathic Le Fort procedures. Maxillary

corticotomies are performed. For patients in primary or mixed dentition, the corticotomies are placed high, above the level of the tooth buds, and stepped around the infraorbital nerve.¹² Complete osteotomies of the pterygoid plate of the affected side are performed using a thin curved osteotome. The contralateral side acts as a “hinge.” A fine guarded osteotome is used to separate the lateral nasal wall and septum. The maxilla is freed but not completely down-fractured. The distractor is applied to the mandible. The vector is oriented parallel with the midsagittal plane but not with the mandibular plane. The distractor is oriented obliquely, downward with a 20–20° tilt, thus elongating the ramus and creating the opening of the bite posteriorly. The maxilla follows the mandible to affect a three-dimensional rotational, vertical elongation.

As the maxilla is moving with and toward the mandible, a mandibular flat plane occlusal splint is inserted to help guide the mandible and maxilla into position. Light Class I box elastics are placed on the right and left sides. After a 5-day latency, the distraction protocol is initiated. The elastics are modified with two 6 oz elastics placed in a Class III orientation on the side of the distraction, and Class I box elastics maintained on the contralateral side as well as a box elastic placed on the anterior. The elastics are changed twice a day and maintained in place for 24 hours a day, except for mealtimes and exercise times. Patients were encouraged to open and close their mouths during the entire DO process, although blenderized diets were prescribed. After 5 to 7 days of distraction, the Class I box elastics on the unaffected, contralateral side are doubled in number to act as a pivot and allow rotation of the maxillary–mandibular complex during distraction as a unit. During the final phases of distraction, the elastic pattern is adjusted, facilitating callus manipulation if indicated. During consolidation, light Class I box elastics are maintained on both sides, and the

mandibular guiding occlusal splint is removed. Distraction continues until the maxilla and mandibular midlines are co-incident with the skeletal midline. For growing patients, the mandible is overcorrected.⁴

Case Example

This case illustrates (Figures 30-19A through 30-19AA) the use of vector modification in order to concurrently move both the maxilla and the mandible in a growing child, thus simultaneously leveling the occlusal plane and correcting the mandibular asymmetry, while at the same time preserving the developing teeth and sensory nerve function.

An 8-year-old female with craniofacial microsomia presented for evaluation. The clinical findings included Grade IIB ramal morphology, mandibular asymmetry, concomitant maxillary deformity, occlusal cant, orbital dystopia, macrostomia, and microtia. Mandibular distraction with concomitant maxillary distraction was used to correct her deformity. The vector of the distractor was designed in such a way as to position the distal mandible to open the occlusion on the right and rotate it over to the left of the midline. This, combined with the loosening of the maxillary complex, led to a simultaneous leveling of the occlusal plane and left overcorrection of the mandibular skeletal position. As she did not have access to orthodontic care, arch bars were ligated to the maxillary and mandibular teeth to act as orthodontic guidance. Interestingly, a developing second molar tooth was in the line of the sagittal osteotomy. During DO, a widening of the follicle was noted.²⁶ Premature eruption of the second molar tooth was also noted, with maintenance of tooth vitality and complete root formation. Inferior alveolar nerve function was completely preserved.

Advantages of Distraction Osteogenesis for Mandibular Advancement

The gradual application of force over time to manipulate and move bones to the desired location is the essence of the distraction technique. Distraction osteogenesis may provide a partial solution for the preservation of condylar function by gradual vectored distraction following orthognathic principles. Patients who should be considered for mandibular advancement using sagittal DO include the following:

- Patients with large mandibular advancements (> 10 mm)
- Patients at risk for TMJ changes as a consequence of BSSO advancement: short, or posteriorly inclined ramus, or high mandibular plane angle
- Patients with existing TMJ disorders



FIGURE 30-19 A, Frontal facial photograph. B, Side facial photograph. C, Open mouth view, showing condylar function. D, Frontal view, showing severe occlusal canting. E, Frontal cephalogram, showing a deficient right ramus and condyle. F, Townes view radiograph. G, Surgical view, showing high-level maxillary osteotomy. H, Midline vascular pedicle. I, Osteotomy steps around the infraorbital nerve. J, Postoperative panoramic view with the distraction osteogenesis completed. K, Postoperative frontal cephalogram with the distraction osteogenesis opened and the occlusion leveled with a vectored distraction device.

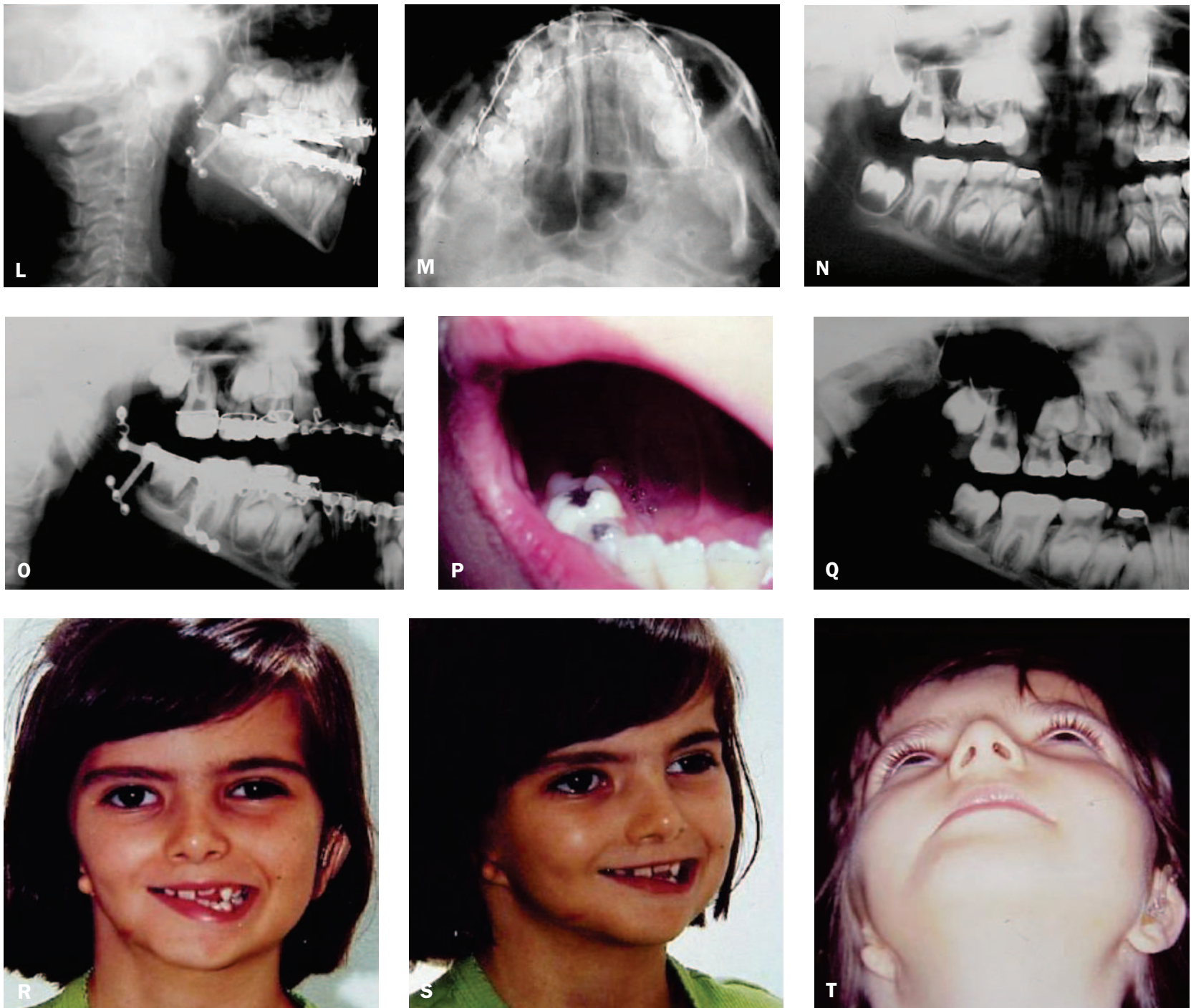


FIGURE 30-19 continued. *L*, Postoperative lateral cephalogram, showing the vector of the distractor and occlusion after callus manipulation. *M*, Postoperative submental vertex view radiograph. *N*, Preoperative panoramic view of an undeveloped tooth in the osteotomy site. *O*, Postoperative panoramic view of a developing tooth bud with widened periodontal ligament. *P*, Postoperative photograph of an erupted developing second molar tooth. *Q*, Final postoperative panoramic view of an erupted developing molar tooth in the distraction site. *R*, Preoperative frontal facial and smiling photograph. *S*, Preoperative oblique facial photograph. *T*, Preoperative worm's eye view photograph.



FIGURE 30-19 continued. U, Postoperative frontal facial and smiling photograph. V, Postoperative oblique facial photograph. W, Postoperative worm's eye view, showing the enhanced symmetry. X, Preoperative frontal canted occlusal plane photograph. Y, Postoperative leveled occlusal plane photograph. Z, Preoperative oblique canted occlusal plane photograph. AA, Postoperative oblique level occlusal plane photograph.

- Patients with asymmetric mandibular advancement, where the risk of condylar torquing exists

The sagittal nature of the osteotomy allows for a faster rate of distraction: 2 mm per day. Similarly, the overlapping nature of the bone cut acts to increase the rate of postdistraction consolidation and ossification. The neurovascular bundle is protected as the buccal and lingual cortices of the sagittal bone cut overlap. There appears to be a predictable and quicker return of neurosensory function of the inferior alveolar nerve, especially for patients of an older age (see Table 30-1).²⁷

The distraction device is designed to facilitate sagittal advancement of the mandible. The mesh

footplates are malleable and easily adapted to place with a periosteal elevator. Monocortical screws are used, thus protecting the teeth, tooth buds, and inferior alveolar nerve. The distraction device is easily removed, as only the footplates are submerged, thus reducing the extent of second-stage surgery. The distractor is located in the buccal vestibule such that device activation can be seen directly. Additionally, the device trajectory can be modified to allow for callus manipulation, without device removal. Ultimately, this distractor can be placed parallel with the midsagittal plane, parallel to the occlusal plane, thus minimizing condylar torque and axis rotation.

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Intraoral Multiaxis Mandibular Distraction Osteogenesis: Clinical Analysis of the First Six Years

Roger Minoretti, Albino Triaca, Michele Antonini and Beat Merz

Distraction osteogenesis (DO) was originally described by Ilizarov as a method in orthopedic applications of the extremities.^{1,2} Already 1989, McCarthy and colleagues demonstrated its successful application in the facial skeleton.^{3,4} Over the past 15 years, the distractors have been improved and the indications for the treatment of dysgnathia by means of DO versus conventional treatment methods have been evaluated and defined. Klein and Howaldt but also McCarthy and colleagues introduced multivector or multi-axial features to extraoral distractors.⁵⁻⁷ Wangerin and Gropp developed an intraoral, submucosal distractor.⁸ Bell and colleagues presented a universal intraoral distractor that could easily be adapted to the clinical and anatomic situation.⁹

It has become apparent that the indications for DO are heavily dependent on the actual distractor. The more simultaneous vectors are available and the more comfortable, safe, and precise an appliance is, the more indications can be found for DO.

In other words, the features of a distractor are decisive for achieving the treatment goals. When applying unidirectional distractors in the mandible, for instance, a deviation from the planned vector makes it impossible to obtain a precise occlusion. In such cases, the appliance must be removed prior to ossification of the callus and the mandible needs to be pulled toward the maxilla with strong elastics. Owing to the premature removal of the appliance, the position of the ramus ascendens and therefore of the condyles cannot be controlled and corrected anymore. The ramus is fully exposed to the forces of the muscles attaching on it. This usually results in a leveling out of the mandibular angle. If the condyles move out of the fossa of the temporomandibular joint (TMJ), a recurring distal occlusion may result, which should not be interpreted as a relapse but as a too-short distraction. This leads to insufficient correction of the distal bite.

Some concurrent extraoral distractors can be controlled in all dimensions. However, their disadvantage is a low acceptance by patients and the remaining facial scars. Also, it is often not possible, for geometric reasons, to reduce the mandibular angle from the beginning of the distraction and onward when using an extraoral device. Only after a certain distraction distance is there sufficient room for maneuvering in an angular direction.

Because of these different drawbacks of existing distractors, we decided in 1997 to develop a distractor for the mandible with the following features:

- A multiaxial design allowing simultaneous lengthening of the mandibular body in a horizontal direction and of the ramus along its axis and a change in the mandibular angle
- An intraoral but extramucosal device that is located lateral to the mandibular molars in the vestibulum
- The distraction mechanism should not be located in direct contact with the osteogenesis zone, and the bicortical bone screws of the fixation plates should not endanger either nerves or tooth roots.
- The distractor mechanism should be removable from the anterior and posterior bone plates and allow exact repositioning afterward.
- The rotational axis for the change of the mandibular angle should be positioned in the line of the osteotomy above the mandible to allow adaptation of the occlusion from the beginning of the distraction and onward.
- The surgical approach should be identical for all indications, with an osteotomy line running from the mandibular angle toward the trigonum retromolare.

A distraction device (Figure 31-1) with these features was developed and was used for the first

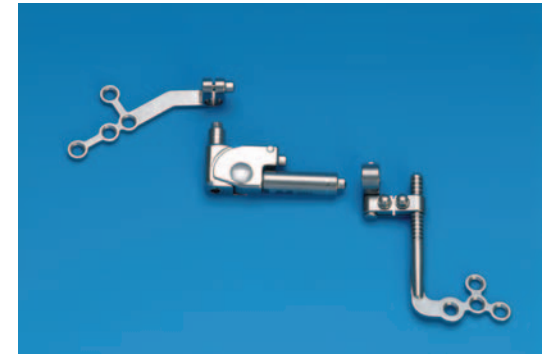


FIGURE 31-1 The multiaxis intraoral distractor.

time in the treatment of an orthognathic patient in 1997.

Material and Methods

MDO-M Distractor

The MDO-M distractor (Orthognathics GmbH, Zurich, Switzerland) (see Figures 31-1 to 31-3) is composed of three parts: a distraction mechanism, an anterior bone plate, and a posterior bone plate. The distraction mechanism, consisting of a horizontal and a vertical distraction cylinder and a gear to change the angle between them, can be used for the left and the right sides, whereas the bone plates are specific to each side. The mechanism is placed extramucosally, lateral to the mandibular molars in the vestibulum, and can be disengaged from the anterior and posterior bone plates (Figure 31-4). The bone plates penetrate the mucosa in the mucobuccal fold of the vestibulum (Figure 31-5) and are fixated to the bone with bicortical bone screws. The anterior bone plate is positioned mesial to the mental foramen and is fixated with three bicortical screws at a sufficient distance from the roots of the anterior mandibular dentition. The posterior plate is fixated to the ramus with three bicortical bone

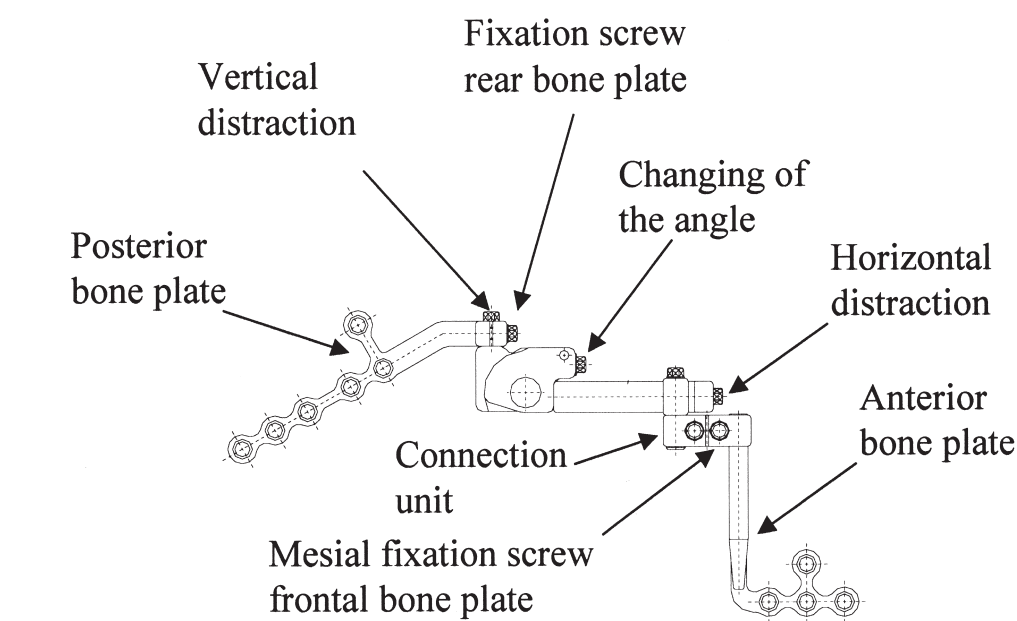


FIGURE 31-2 Diagram of the distraction device. Reproduced with permission from Samchukov ML, Cope JB, Cherkashin AM. Craniofacial Distraction Osteogenesis. Mosby Inc; 2001.

screws cranially to the mandibular canal and, if desired, with a further screw caudally to the canal.

At the posterior bone plate, the mechanism can be rotated about a vertical axis to adjust the

horizontal distraction vector parallel to the sagittal plane (Figure 31-6). This has the advantage that when lengthening the body of the mandible, the transversal distance between the condyles remains constant and the relationship between



FIGURE 31-3 The multiaxis intraoral distractor. Device on a plastic model.

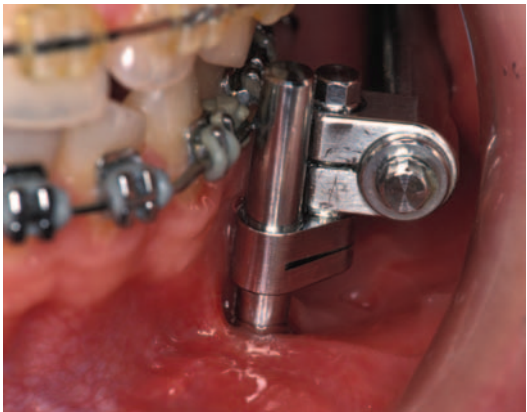


FIGURE 31-5 The bone plates penetrate the mucosa in the mucobuccal fold of the vestibulum.



FIGURE 31-4 A, The mechanism can be removed and reinserted without losing the correct relationship between the anterior and the posterior plate. B, The distraction mechanism.



FIGURE 31-6 The mechanism can be rotated about a vertical axis to adjust the horizontal distraction vector parallel to the sagittal plane.

the condyle and fossa at the TMJ remains unchanged. Through this adjustability about the vertical axis, a midline deviation between the mandible and the maxilla can also be corrected.

The distractor has three different activation possibilities:

1. The anteriorly oriented distraction to lengthen the mandibular body (Figure 31-7)
2. The caudally oriented distraction for lengthening the ramus mandibulae (Figure 31-8)
3. The change in the angle between the two linear vectors to adjust the occlusion gradually (Figure 31-9)

The mechanism is initially placed in such a way that the anteriorly oriented distraction runs parallel to the occlusal plane. For this distraction of the mandibular body, two distraction cylinders are available: one of 11 mm and one of 15 mm distraction length. The distraction distance can be lengthened by moving the fixation of the anterior bone plate along the horizontal cylinder by an additional distance of up to 10 mm, depending on the case. The vertical distraction cylinder provides a distraction of 7 mm. The angle between the two cylinders can be changed by 30° in total.

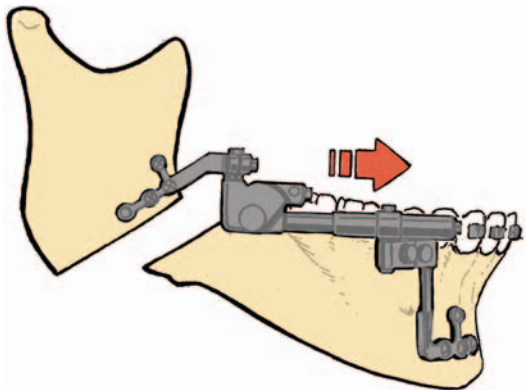


FIGURE 31-7 Horizontal distraction. Courtesy of M. Haab. Reproduced with permission from Samchukov ML, Cope JB, Cherkashin AM. Craniofacial Distraction Osteogenesis. Mosby Inc; 2001.

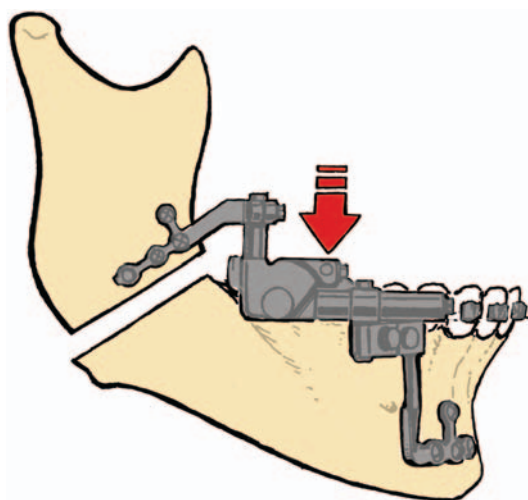


FIGURE 31-8 Vertical distraction. Courtesy of M. Haab.

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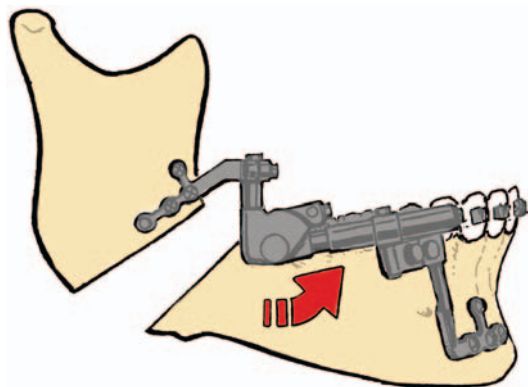


FIGURE 31-9 Angular distraction. Courtesy of M. Haab.

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By virtue of the multiaxial arrangement of the distraction vectors, it becomes possible with only one distractor to change the body and the ramus of the mandible and the mandibular angle. Preoperative planning of the vectors and its transfer during the surgery is unnecessary as the vectors can be adjusted to the desired directions during the distraction. The occlusion is the relevant reference. Therefore, the distractor can be implanted in all patients, always with the same, standardized routine. Also, the osteotomy line is always the same from the mandibular angle to the trigonum retromolare. At the end of the retention, the mechanism can be loosened from the anterior and posterior bone plates and removed (see Figure 31-4). In this manner, the stability of the zone of osteogenesis can be evaluated (Figure 31-10).



FIGURE 31-10 Panoramic radiograph at the end of the retention phase. The mechanism can be loosened from the anterior and posterior bone plates and removed. In this manner, the stability of the zone of osteogenesis can be evaluated.

Surgical Technique

The MDO-M distractor is usually inserted under general anesthesia. In our patients ($N = 77$), the distractor was only once inserted under local anesthesia.

First, a 2 cm-long incision down to the bone is conducted in the vestibulum along the anterior edge of the ramus. The periosteum is cautiously elevated on the buccal side and the lingual side down to the mandibular angle. On the lingual side, the periosteum is elevated with a spatula in the area of the osteotomy respectively the fracture. Then a corticotomy is conducted on the buccal side with a fine rotating bone bur, leading from the mandibular angle to the trigonum retromolare. On the lingual side, only the first 8 mm is cut. It is important to cut the lower edge of the mandibular angle completely below the inferior alveolar nerve up to and including the lingual cortical bone. If necessary, we use a transbuccal approach, protecting the soft tissues with a drilling sleeve and using a fine rotating bone bur with a long shaft (Figure 31-11). Without the transbuccal access, this zone can also be cut with an angled piezoelectric osteotome.

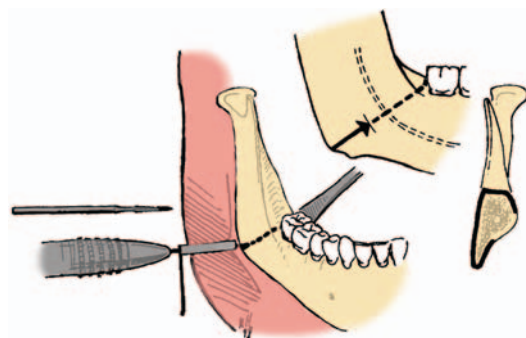


FIGURE 31-11 Diagram indicating the location of the osteotomy at the mandibular angle. Courtesy of M. Haab.

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Prior to the fracture of the mandible in the area of the corticotomy, the posterior bone plates of the distractor are inserted. The posterior bone plate is fixated about parallel to the corticotomy line with three transbuccally inserted bicortical bone screws on the cranial side of the mandibular canal and, if desired, a further screw caudal to the mandibular canal on the ramus. In our experience, it is advantageous to mount the distractor provisionally to the posterior bone plate during its fixation to arrange the plate such that the horizontal distraction cylinder is parallel to the occlusal plane. The desired distraction vectors are irrelevant at this time as they can be adjusted later.

To insert the anterior bone plate, an incision is placed in the mucobuccal fold of the vestibulum in the area of the canine, sparing the ramus labialis of the mental nerve. The anterior plate is fixated mesial to the mental foramen with three bicortical bone screws, at a sufficient distance below the apices of the roots of the anterior dentition (Figure 31-12). The anterior incision is closed with a suture, and then the distraction mechanism is inserted between the anterior and the posterior bone plates. It is now possible to remove the mechanism and reinsert it later in exactly the same position.

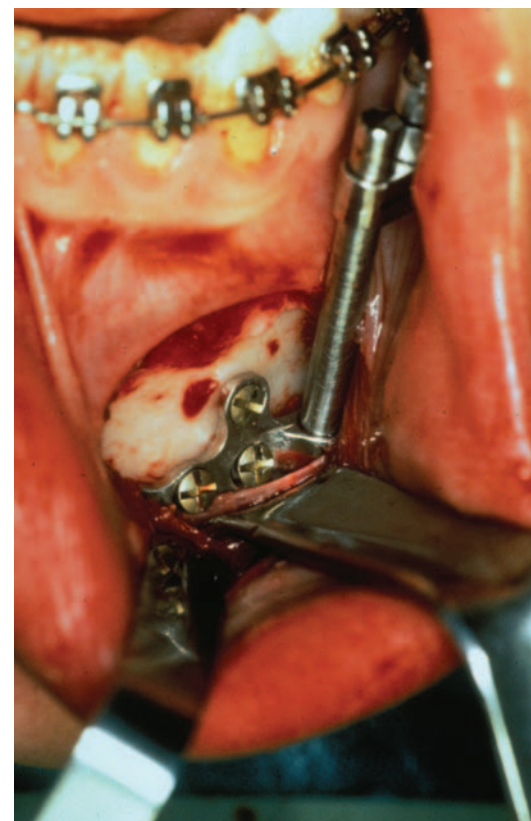


FIGURE 31-12 The anterior plate is fixated mesial to the mental foramen with three bicortical bone screws at a sufficient distance from the roots of the anterior dentition.

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The same procedure is followed on the other side. For the fracture of the mandible in the area of the corticotomy, again, the distractor mechanism is removed. The fracture is accomplished by a rotation with a wide chisel on the upper edge of the mandible. Often it is necessary to complete the fracture with a special spreading instrument (Figure 31-13) or a kind of screwdriver below the nerve canal (Figure 31-14). Especially in younger patients with elastic bone characteristics, it is often not simple to totally cut through the mandible in the area of the mandibular angle. For a successful distraction, the two bone segments must be completely separated; a greenstick fracture would result in complications. The inferior alveolar nerve remains intact.

Now the posterior incision is sutured (Figure 31-15), and the distraction mechanism is repositioned precisely on the anterior and posterior bone plates. At this point, the midline relationship between the maxilla and the mandible is controlled. Then the other side of the mandible is fractured in the same described sequence.

In the case of a simultaneous Le Fort I osteotomy, the mandible is fractured only after the positioning of the maxilla. This way, the mandible can serve as a definite reference for the positioning of the maxilla.



FIGURE 31-13 The special spreading instrument.

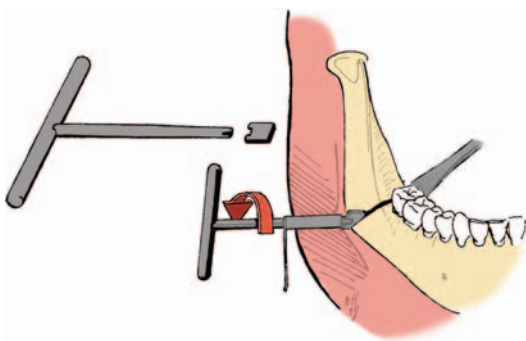


FIGURE 31-14 Diagram demonstrating completion of the osteotomy with a bone spreader. Courtesy of M. Haab.

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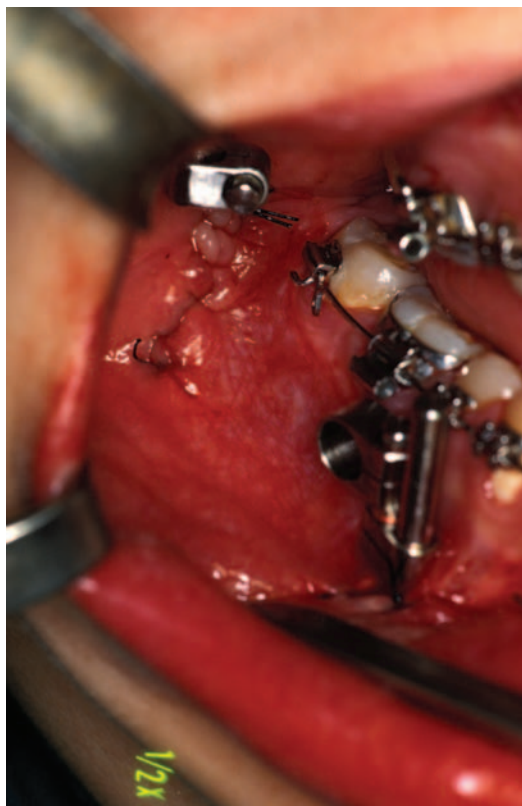


FIGURE 31-15 Closure of the soft tissues after temporary removal of the distractor mechanism.

After the insertion of the intraoral multiaxis distractor, the patient can leave the clinic on the same day. If the operation was combined with a Le Fort I osteotomy, the patient remains in the clinic for 3 days. The patient remains on an antibiotic regimen for 5 days, usually clindamycin.

Distraction Protocol

Latency Period

The latency period is 7 days.

Distraction Phase

Distraction of 0.5 up to 1.0 mm per day in steps of 0.25 mm spread over 24 hours or rotation of the angle of 3° per day. Duration until reaching the desired occlusion.

Control visits are recommended two times per week.

The patient or his or her relatives activate only the horizontal distraction cylinder. During the control visits, the vertical cylinder and the angle are distracted according to requirements.

A temporary sagittal overcorrection of 0 to 3 mm relative to the incisal edges is recommended for about 4 days (Figure 31-16). Then in one visit, the correct occlusion is achieved by backward turning of the horizontal distraction cylinder and closing of an open bite by rotation with the angulation gear.



FIGURE 31-16 Temporary sagittal overcorrection of 3 mm relative to the incisal edges.

Retention Phase

The retention phase is 12 weeks, with follow-up controls every 1 to 2 weeks.

Removal of the Distractors

At the end of the retention phase, the mechanism is loosened from the anterior and posterior bone plates and removed to clinically test the stability of the osteogenesis zone.

The removal of the anterior and the posterior bone plates is done ambulatory under short general anesthesia or under local anesthesia.

If a genioplasty is indicated, it is preferably combined with the removal of the bone plates because now, after the correction of the distocclusion, the facial profile may again be evaluated, and for surgical access, only the two anterior incisions for the plate removal need to be connected.

Indications

The majority of patients with a misalignment of jaws can be treated with standard surgical methods, such as a sagittal split osteotomy, Le Fort I osteotomy or a combination of both methods. We see the indication for a mandibular distraction in extreme malpositions, which often result in a recurrence in the postoperative course. The indications for a correction of the mandible are listed below.

- Large sagittal step of 12 mm or more and/or
- Preoperative degenerative changes in the TMJs (radiologic diagnosis by means of computed tomography [CT] or volumetric tomography) and/or
- Correct position of the maxilla combined with an increased mandibular angle, skeletal and dental Class II occlusion and a dental open bite

Analysis of the Patient Population

Between December 1997 and June 2004, 77 patients were treated with the MDO-M distractor

in our clinic (51 females and 26 males). The average age was 19 years 8 months (10 years 7 months to 47 years 8 months).

Preoperative Diagnoses

- Five patients with relapse after a sagittal split
- 48 patients with a degenerative change in the TMJs
- 34 patients with a combined false position of the mandible and the maxilla
- 19 patients with correct position of the maxilla but open distocclusion (overbite zero or negative)

All 77 patients had a distocclusion. The overjet was, on average, 12.0 mm prior to the distraction; the overbite prior to distraction was, on average, 1 mm.

Indications

- Large sagittal step (12 mm average overjet)
- Preexisting degenerative changes in the TMJs for 48 of 77 patients
- Correct position of the maxilla together with a large mandibular angle and open distocclusion in 19 of 77 patients

Orthodontic Pretreatment

The dental arches were precoordinated by the orthodontist with fixed appliances such that after distraction, including the correction of the distocclusion by means of the angulation gear, the desired occlusion was immediately reached in most cases.

Surgery

In all patients, an MDO-M distractor was inserted bilaterally. In 34 patients, the maxilla was repositioned simultaneously with a Le Fort I osteotomy during the insertion of the distractors. In six patients, a simultaneous genioplasty was performed, whereas in 32 patients, the genioplasty was done only at the time of removal of the distractors. In 19 patients with an open distocclusion (overbite 0 or negative) and correct position of the maxilla, the mandibular false position was corrected only by means of distraction. In 2 patients, the bite was opened up by means of a Le Fort I osteotomy in accordance with the facial planning; subsequently, a correct occlusion was achieved by means of the distraction.

Latency Period

The latency period was, on average, 6.5 days.

Distraction Phase

The distraction phase was, on average, 21 days.

Retention Phase

The retention phase was, on average, 84 days.

Measurements

Preoperatively, at the beginning of distraction, and postoperatively, at semiannual intervals, the occlusal parameters were measured. We evaluated overjet, overbite, midline, occlusal plane, dental class, maximal mouth opening, protrusion, and laterotrusion. Furthermore, we tested the sensitivity in the innervation area of the inferior alveolar nerve and evaluated the status of the TMJs. Overjet, overbite, midline, and dental class were measured in the retruded contact position. Panoramic radiograph and lateral cephalogram were taken preoperatively, before the start of distraction, at the end of the distraction phase, after the retention phase, after removal of the distractor, and at the semiannual follow-up controls. The measurements were systematically taken on the basis of the dental parameters as described above. The superimposition of the preoperative and postoperative follow-up lateral cephalometric radiographs was not made consistent in all cases.

Results

The average follow-up over all 77 patients was 2.1 years. After this time, the overjet was, on average, 3 mm and the overbite was 1.6 mm. The maximal mouth opening was 43 mm, the protrusion was 8 mm, and the laterotrusion to both sides was 9 mm.

As a result of the treatment, the overjet was reduced 9 mm, on average, and the overbite increased by 0.6 mm over the average follow-up time.

Change in the Occlusion in the Long-Term Follow-Up

In 10 patients (13%; 9 females, 1 male), a change in the occlusion with an increase of the overjet by 3.7 mm and a reduction in the overbite by 1.3 mm could be observed during the course of the follow-up time (2.3 years on average). In the other 67 patients (87%), the result was stable over the follow-up period (2 years on average).

Six changes were noted in the patient group with simultaneous Le Fort I osteotomy, two in the group with mandibular distraction only and a preoperatively closed bite (overbite larger than zero), and two in the group with mandibular distraction only and a preoperatively open bite (overbite smaller or equal to zero). In three patients, the overjet increased in the state of relapse after sagittal split and subsequent reoperation with distraction. A stable result, maintained after an average follow-up of 2 years, could be reached in both patients with an open bite after opening the bite by means of Le Fort I osteotomy and rotation of the mandible to close the bite in a counterclockwise direction by means of the multiaxis distractor.

Complications

Incomplete Ossification of the Osteogenesis Zone

In six patients (7.8%), the osteogenesis zone was subject to an incomplete ossification, resulting in an elastic behavior of the mandible after removal of the distractor. The average retention phase in this group was 132 days. Despite the prolonged retention phase, a stable callus could not be obtained such that at the time of distractor removal, autologous bone was inserted and the zone was stabilized by means of bone plates. In all patients of this group, finally, a stable result was achieved (follow-up 1.8 years on average). The average age of this patient group was 30 years.

Incomplete Separation of the Mandibular Segments during Surgery

In four patients, the mandible was not completely separated in the area of the mandibular angle (greenstick fracture). In these patients, the osteotomy had to be completed in a second intervention at the beginning of the distraction phase.

In two patients, this greenstick fracture was noted too late, resulting in a consolidation in an undesired position, with flattening of the mandibular angle and slight open bite in one patient. In the other patient, the mandible could not be distracted.

Nerve Injuries

In all 77 patients, the inferior alveolar nerve and the lingual nerve could be spared. Some patients had a transient hyposensitivity in the mental area, which was, however, not disturbing them. None of the patients suffered a complete loss of sensation.

Discussion

With a mandibular multiaxis distractor, only patients who had an extreme distocclusion and/or a preexisting arthrosis of the TMJs and/or an open distocclusion were treated. In these patient groups, we preferred mandibular distraction because experience shows that under these conditions, often no stable result is achieved, with a sagittal split osteotomy, and a high risk of a relapse is typical.^{10–26} With the sagittal split, the length of the mandibular forward displacement is relevant for the long-term relapse.^{27–30} Arnett described condylar resorption as the main reason for potential long-term relapse.³¹ Given that a relapse usually manifests itself within the first 12 months,³² the average follow-up time of 2.1 years is sufficient for a definite finding. The first patients treated could be followed up to 6 years. For the analysis of the results, all patients who were

treated with the multiaxis distractor in our practice were included in the statistics and analyzed. As we developed the distractor ourselves, we had the advantage of knowing very well the functioning of the device and the related surgical technique. However, when interpreting the results, nevertheless, a certain learning curve must be taken into account. For instance, the osteotomy technique has been improved since the start, and specific instruments were developed for the minimally invasive osteotomy and the final fracture of the mandible. Juvenile patients have an elastic bone, which often proved to be difficult to fracture. This is of importance specifically in the area of the mandibular angle.

Also, the actual distraction technique with the multiaxis device was optimized with an increasing number of patients. For instance, a temporary sagittal overcorrection of up to 3 mm over the edge-to-edge relationship of the incisors has proved to be of value for finally achieving a stable bite. With this technique, an additional expansion of the soft tissues was possible. This overcorrection was maintained for 4 days and then reversed to a correct occlusion in one control visit. Therefore, the mandibular angle could be reduced without resistance and the bite closed. Furthermore, the callus could be compressed.

The design of the distractor proved its value with respect to concept and design from the beginning. All dysgnathic positions could be corrected and brought to the correct occlusion by using only the activation of the distraction cylinders or, in the case of midline deviations, by means of and adjustment of the distractor during a short-term (20 minutes) intermaxillary fixation (Figure 31-17). Thanks to the precise modification possibilities of the distraction vectors, no undesired open bites were apparent, on average,

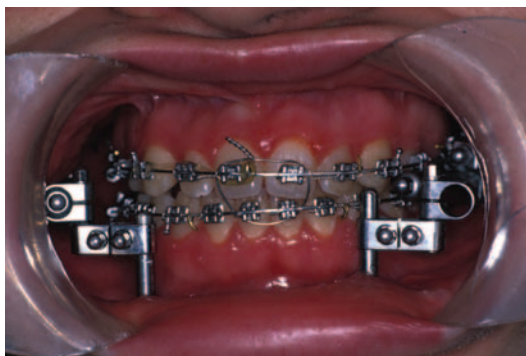


FIGURE 31-17 In case of a midline deviation, the occlusion is adjusted by placing a temporary (about 20 minutes) intermaxillary fixation so that all fixation clamps can be released and retightened passively in the new position. The intermaxillary fixation is then removed.

over all patients ($n = 77$). The overbite increased, on average, by 0.6 mm ($N = 77$; average follow-up of 2.1 years). Even in the patient group with mandibular distraction without a Le Fort I osteotomy, with an initial negative or zero overbite, the overbite could be increased by 1.8 mm on average (average follow-up of 2 years).

Summary

From December 1997 until June 2004, 77 patients were treated with the MDO-M intraoral multiaxis distractor (51 females, 26 males). The average age was 19 years 8 months (minimum 10 years 7 months, maximum 47 years 8 months). All patients had a high risk of relapse according to their initial diagnosis. The overjet was, on average, 12 mm (maximum 20 mm, minimum 4 mm) prior to distraction. Preoperatively, 48 of 77 patients had an arthrosis of the TMJs as documented with CT. Nineteen of 77 patients had a dental open distocclusion with an average overbite of -1.4 mm (minimum 0 mm, maximum -4 mm). The latency period was, on average, 6.5 days, the distraction phase was 21 days, and the retention phase was 84 days. A temporary sagittal overcorrection of 1.3 mm over the edge-to-edge relationship of the incisors was implemented and maintained over 4 days. Afterward, the overcorrection was corrected back into a correct occlusion in one visit. Thanks to the vector-controlled multiaxial distraction of the mandible, the occlusion could be arranged precisely. The distractor proved its function in all phases of the treatment.

The patient follow-up was, on average, 2.1 years (maximum 6 years, minimum 3 weeks). The overjet was, on average, 3 mm, and the overbite was 1.6 mm. The treatment reduced the overjet by 9 mm, and the overbite was increased by 0.6 mm.

Changes in the occlusion were found in 10 patients. The overjet was increased, on average, by 3.7 mm, and the overbite was reduced by 1.3 mm (average follow-up of 2.3 years).

Sixty-seven patients showed stable occlusal relationships after an average follow-up of 2 years. In this group, the overjet was reduced by 9.5 mm on average, and the overbite increased by 0.7 mm. In two patients, a Le Fort I osteotomy was conducted to open the bite, and then the mandible was distracted into a correct occlusion, according to the facial planning. Both patients showed a stable occlusal situation after 2 years.

Case Reports

Case 1: Bilateral Mandibular Distraction

Case 1 is a 17-year-old woman with a skeletal Class II occlusion and an overjet of 17 mm

(Figure 31-18). According to the preoperative facial planning, the mandible was bilaterally distracted into the desired position and occlusion with an intraoral multiaxial distractor on both sides. The latency period was 5 days, the distraction phase was 31 days, and the retention phase was 70 days. The distractors were removed after 106 days in situ. Two displaced third molars in the mandible were left in place as the distraction created new space in the retromolar area, allowing correct positioning. In this fashion, the upper second molars could be occlusally supported. The patient follow-up was 6 years. The result remained skeletally and dentally stable. No problems with the TMJs were noted in the follow-up.

Case 2: Bilateral Mandibular Distraction, Le Fort I Osteotomy, and Genioplasty

Case 2 is a 33-year-old female with a skeletal Class II occlusion, a low positioning of the maxilla with 6 mm exposure of the frontal dentition, and degenerative arthritic changes in the TMJs (Figure 31-19). An MDO-M distractor was inserted on both sides, and, simultaneously, the maxilla was impacted by means of a Le Fort I osteotomy. The overjet was 9 mm after the Le Fort I osteotomy. The latency period was 5 days, the distraction phase was 13 days, and the retention phase was 71 days. The distractors were removed after 89 days. At the time of the distractor removal, a simultaneous genioplasty was performed. The patient follow-up was 4.5 years. The result remained skeletally and dentally stable. Since the surgery, no further acute inflammation was noted in the arthritic TMJs, and the patient remained without disorders.

Case 3: Bilateral Mandibular Distraction, Le Fort I Osteotomy, and Genioplasty

Case 3 is a 19-year-old female with a skeletal Class II occlusion, a low positioning of the maxilla, and a degenerative arthritic change with dysplastic joint heads at the TMJs (Figure 31-20). The overjet was 9 mm preoperatively, and a slight open bite was noted in the front, with an overbite of -0.5 mm. According to the facial planning, the maxilla was rotated counterclockwise by means of a Le Fort I osteotomy; therefore, the open bite increased. At the same time, an MDO-M distractor was implanted on both sides. The overjet after the Le Fort I osteotomy was 14 mm, and the overbite was -1.5 mm. The latency period was 7 days, the distraction phase was 23 days, and the retention phase was 71 days. The closing of the bite was achieved solely with the multiaxis distractor during the distraction phase, and a correct occlusion could be reached. The distractors were removed after 105 days. At the time of distractor



FIGURE 31-18 A 17-year-old female patient with a skeletal Class II occlusion and a 17 mm overjet. A and B, Preoperative and postoperative profile photographs. C and D, Preoperative and postoperative lateral cephalometric radiographs. E and F, Preoperative and postoperative panoramic radiographs. Two displaced third molars in the mandible were left in place as the distraction created new space in the retromolar area. In this fashion, the upper second molars could be occlusally supported. G and H, Intraoral anterior photographs preoperatively and final occlusion 5 years after distraction. I and K, Intraoral lateral photographs preoperatively and final occlusion 5 years after distraction.

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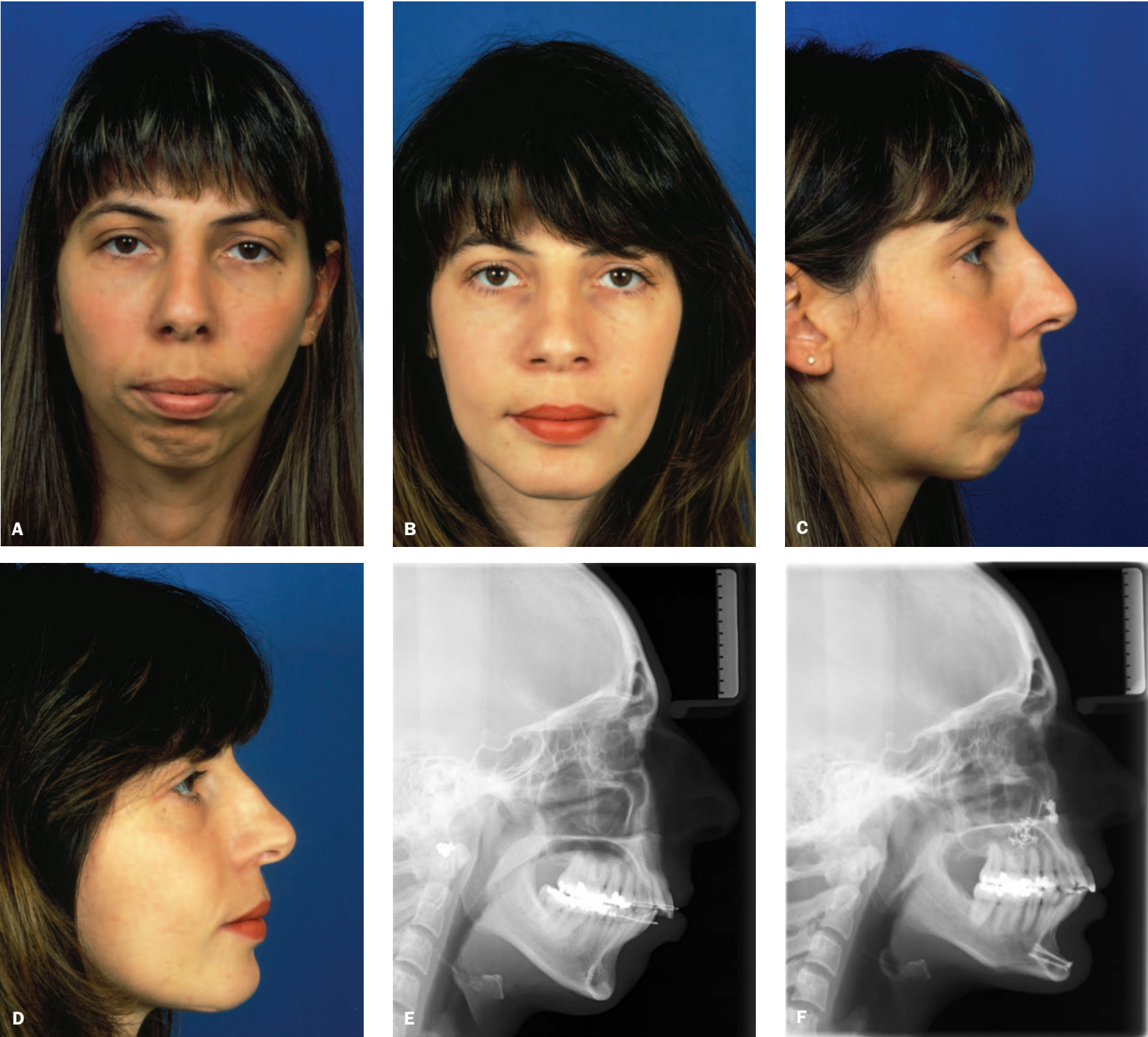


FIGURE 31-19 A 33-year-old female patient with a skeletal Class II occlusion and a low positioning of the maxilla with 6 mm of incisor exposure, bilateral temporomandibular joint arthritis, and an overjet of 9 mm after the Le Fort I osteotomy. A and B, Preoperative and postoperative frontal photographs. C and D, Preoperative and postoperative profile photographs. E and F, Preoperative and postoperative lateral cephalometric radiographs. G and H, Intraoral anterior and lateral photographs 4 years after distraction. Reproduced with permission from Samchukov ML, Cope JB, Cherkashin AM. Craniofacial Distraction Osteogenesis. Mosby Inc; 2001.





FIGURE 31-20 A 19-year-old female patient with a skeletal Class II occlusion, a low positioning of the maxilla, and bilateral temporomandibular joint (TMJ) arthritis with dysplastic joint heads at the TMJs. The overjet was preoperatively 9 mm, and there was a slight open bite in the front, with an overbite of -0.5 mm. The overjet after the Le Fort I osteotomy was 14 mm; the overbite was -1.5 mm. A and B, Preoperative and postoperative profile photographs. C and D, Preoperative and postoperative lateral cephalometric radiographs. E, The superimposition of the preoperative (white) and postoperative (red) lateral cephalometric radiographs. According to the facial planning, the maxilla was rotated counterclockwise by means of a Le Fort I osteotomy; therefore, the open bite increased. The closing of the bite was achieved solely with the multiaxis distractor during the distraction phase. F, Oblique photograph: the patient during the retention phase still wearing the distractors. G and H, Intraoral anterior and lateral photographs 3 years after distraction.

removal, a genioplasty was conducted. The follow-up was 3.5 years. The result remained skeletally and dentally stable. The overjet was 2.5 mm, and the overbite was 4 mm at the last control visit. Since the treatment, there have been no further acute inflammations of the TMJ, and the patient remains free of TMJ disorder.

Case 4: Bilateral Mandibular Distraction, Le Fort I Osteotomy, and Genioplasty

Case 4 is a 14-year-old female with a skeletal Class II occlusion owing to micromandibula as a consequence of a mandibular trauma in early childhood (Figure 31-21). There was also a low

positioning of the maxilla. An MDO-M distractor was inserted on both sides, and, simultaneously, the maxilla was repositioned with a Le Fort I osteotomy into a desired position according to facial planning. The overjet was 15 mm after the Le Fort I osteotomy. The latency period was 7 days, the distraction phase was 18 days, and the retention phase was 90 days. A correct occlusion was achieved with the distractors. At the time of distractor removal, a simultaneous genioplasty was conducted. The follow-up was 3 years. The occlusion changed slightly during these 3 years, most likely because of additional growth and dental movements. The overjet increased by 3 mm. The esthetic result remained stable. The patient has no TMJ problems.

Case 5: Bilateral Mandibular Distraction

Case 5 is a 15-year-old female with an open distocclusion and a degenerative arthritic change in both TMJs (Figure 31-22). The overjet was 12 mm, and the open bite was –2 mm in the front. According to the preoperative facial planning, the mandible was distracted into the correct position by means of the MDO-M multiaxis distractor. The latency period was 7 days, the distraction phase was 27 days, and the retention phase was 88 days. The distractor was removed only 2 months previously; therefore, no statement can be made on the long-term follow-up. The desired occlusion could be achieved precisely, and there were no problems with the TMJs.



FIGURE 31-21 A 14-year-old female patient with a skeletal Class II owing to micromandibula as a consequence of a mandibular trauma in early childhood. There was also a low positioning of the maxilla. A and B, Preoperative and postoperative frontal photographs. C and D, Preoperative and postoperative profile photographs. E and F, Preoperative and postoperative lateral cephalometric radiographs.



FIGURE 31-22 A 15-year-old female patient with an open distocclusion and bilateral temporomandibular joint arthritis. The overjet was 12 mm, and the open bite was -2 mm in the front. A and B, Preoperative and postoperative profile photographs. C and D, Preoperative and postoperative lateral cephalometric radiographs. E and F, Intraoral anterior photographs of preoperative and postoperative occlusion. G and H, Intraoral lateral photographs of preoperative and postoperative occlusion.

Acknowledgments

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Surgical Orthodontics in Mandibular Lengthening

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Combining orthodontics to diagnose and prepare the dentition three-dimensionally, applying the proper instrumentation and technology with surgery for mandibular advancement to correct Class II malocclusion with mandibular deficiency, is a very popular method in the treatment of dentofacial deformities. However, many patients pose several difficulties, challenging both specialties and producing limited results, with severe relapse, condylitis, temporomandibular arthrosis, and total failures. The experienced surgeon knows the limitations of orthognathic surgery in several clinical situations and understands the consequences of poor outcomes and failures after applying the traditional surgical techniques in those patients.

Unlimited progressive stretching of the distraction callus within a controlled environment in a dentition orthodontically treated and carefully unloading the detrimental reciprocal forces within the temporomandibular joints (TMJs) allow us to treat a variety of clinical situations forbidden in the past. Large advancements without the fear of relapse; TMJ irreversible damage; mandibular advancements in large, unknown amounts, such as for sleep apnea, in which we ignore the amount of millimeters to advance before we definitively correct the breathing problem; the presence of inadequate anatomy or secondary advancements after failures; and severe deficiencies in children are particular situations with an obscure prognosis if treated with traditional surgery.

Since its introduction in 1953 by Hugo Obwegeser, mandibular sagittal split osteotomy with its modifications continues to be the favorite surgical technique to advance the mandible and is a simple, straightforward procedure that is economical and predictable and has a very low morbidity. Orthodontists are very familiar with the method, and it is very popular nowadays, even though there are several clinical definite indications and contraindications to avoid complications and failures.

Mandibular Lengthening

Clinical Indications and Selection of Patients

Traditional orthognathic surgery for mandibular advancement has limitations in several circumstances in which distraction osteogenesis represents a better technique in terms of predictability and stability (Figures 32-1 through 32-3).¹⁻⁴

The indications for mandibular lengthening include major advancements, TMJ degenerative joint disease as a precondition, sleep apnea (need for titration of the advancement), inadequate mandibular anatomy for conventional bilateral sagittal split osteotomies (BSSO), secondary mandibular advancements (relapse of mandibular advancements by BSSO), and

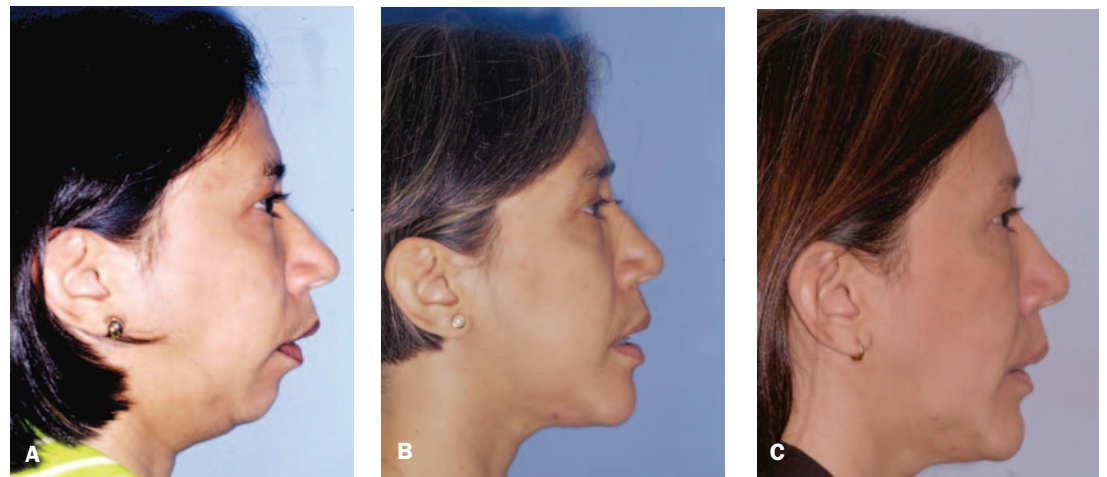


FIGURE 32-1 A 34-year-old patient with bilateral temporomandibular joint degenerative disease in combination with mandibular and chin anterior-posterior deficiencies. Profile view sequence. A, Preoperative. B, After bilateral mandibular lengthening and two-step advancement genioplasty. C, At the 7-year follow-up.



FIGURE 32-2 Cephalometric radiograph sequence. A, Preoperatively. B, After the activation period. Observe distractors parallel to the occlusal plane. C, Seven years later.

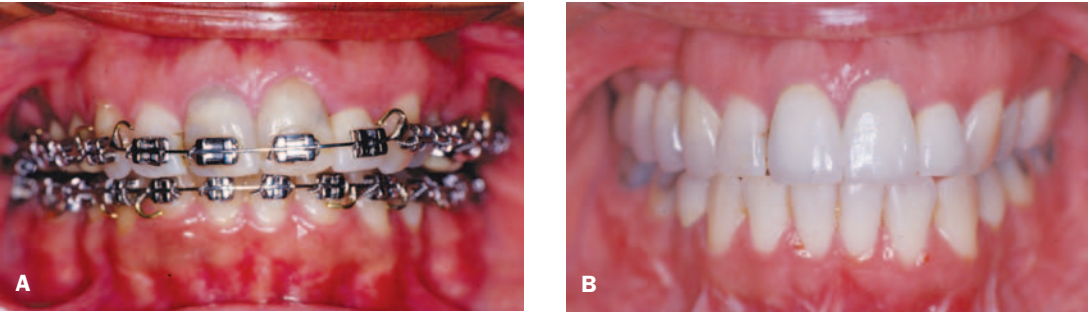


FIGURE 32-3 Preoperative and 7-year follow-up dental views. Observe the adequate occlusion and dental midlines achieved through mandibular lengthening by distraction osteogenesis in a predictable manner.

children with severe mandibular deformities (eg, Pierre Robin, ankylosis).⁵⁻⁸

Surgical Planning

The adequate positioning of the distraction is fundamental to achieve the correct distraction vector, and different variables are taken into consideration for adequate planning and fixation. Obviously, the possibility of changing the distraction vector after surgery is sometimes required for an ideal functional-esthetic outcome.

Preferably, minimal changes should be needed at the end of the activation phase to obtain adequate occlusion.

It must be considered that most patients with a Class II malocclusion have a three-dimensional deficiency (micromandibulism), including a severe curve of Spee and moderate to severe dental crowding, where there is no space to accommodate teeth in a stable manner.⁹ The alveolar bone is also deficient, not permitting the incisors and canines to be moved anteriorly, producing major gingival recessions. Sometimes premolar extraction is indicated, increasing the overjet and making the intercuspitation difficult, allowing a Class III molar and a Class I canine at the end of the treatment.

The orthodontist defines the functional occlusal plane and the need to flatten it either by orthodontic means or if it is necessary to include a subapical osteotomy with inferior repositioning; the severe curve of Spee problem needs to be diagnosed and treated to have an ideal occlusal plane at the beginning of the activation phase, allowing full dental intercuspitation when the activation period is over.

Commonly, a transverse mandibular deficiency is also present, as previously mentioned; for minimal discrepancies between the upper and the lower arches, orthodontic movements at the molar level would allow an adequate relationship between the arches. If no crowding exists and the transverse discrepancy does not exceed 5 mm, a midsymphyseal osteotomy could be performed, with expansion and stabilization for 6 weeks with a lingual acrylic splint; however, the necessity of performing a simultaneous BSSO to avoid lateral

displacement of the condyles must be carefully assessed. In moderate or severe deficiencies, mandibular widening by distraction osteogenesis, the creation of an interdental space to treat the dental crowding could be indicated in the same surgical procedure (Figures 32-4 through 32-10).

The orthodontist and surgeon should plan the positioning of the distraction appliance based on photographs, radiographs, dental models mounted in an articulator, and the clinical examination, sometimes requiring a three-dimensional model. The distractors need to be parallel to the occlusal plane to avoid developing a posterior or anterior open bite.

Additionally, as the mandible is transversely wider in the posterior and narrower in the anterior portion, the distractor appliances need to be adjusted by creating a step of 5 to 8 mm in the anterior fixation arms, allowing the distractor's screw to be placed parallel to the axis of distraction (strict anterior-posterior direction) to compensate for this important variation in mandibular width (see Figures 32-2 and 32-5). If this is underestimated, the reciprocal forces exerted to the mandible by the appliance will advance the mandible, moving the proximal segment not only posteriorly (this situation could be overcome with the use of heavy Class II



FIGURE 32-4 A–C, Preoperative facial views of a 17-year-old patient with bilateral temporomandibular joint degenerative disease in conjunction with transverse and anterior-posterior mandibular deficiency, along with anterior-posterior chin deficiency. D–F, Four years after simultaneous genioplasty, mandibular widening and lengthening were performed.

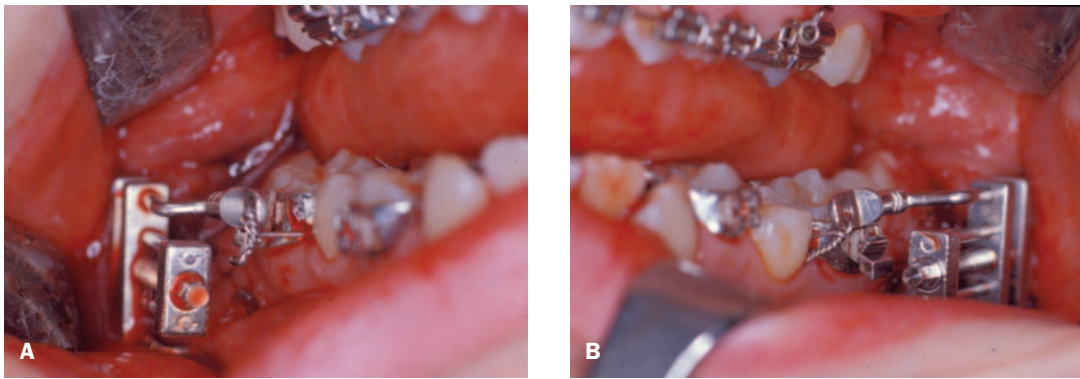


FIGURE 32-5 Intraoperative view after distractor fixation. The appliances' screws are placed parallel to the occlusal plane to avoid open-bite development. Observe the bent anterior arms of the distractors to achieve a 0° angle on the axial plane, avoiding detrimental forces to the temporomandibular joint; the devices must be parallel to each other. Note the bands of the dental-borne appliance used for mandibular widening.

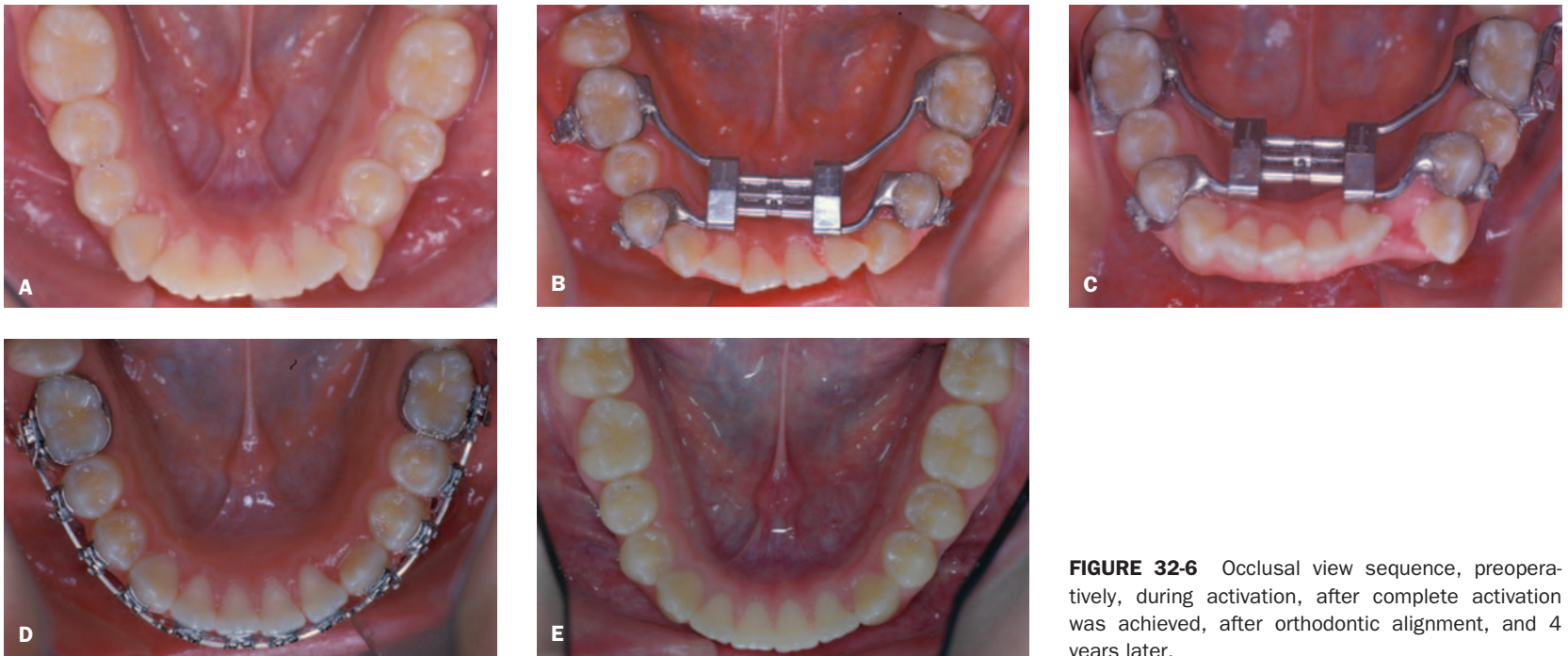


FIGURE 32-6 Occlusal view sequence, preoperatively, during activation, after complete activation was achieved, after orthodontic alignment, and 4 years later.



FIGURE 32-7 Lateral cephalometric sequence. A, Preorthodontic surgical treatment. B, Immediately after surgery. Adequate alignment of the maxillary arch was achieved before surgery with a correct SN-1 angle, increasing the overjet. Observe the parallelism between the appliances and the occlusal plane to avoid open bites. C, When transmucosal placement of the devices is not possible, a fork end in the posterior-inferior arm is used; this allows pulling out the distractor, leaving these screws in place and avoiding wound reopening. Observe the posterior-inferior screws in place 4 years after surgery.

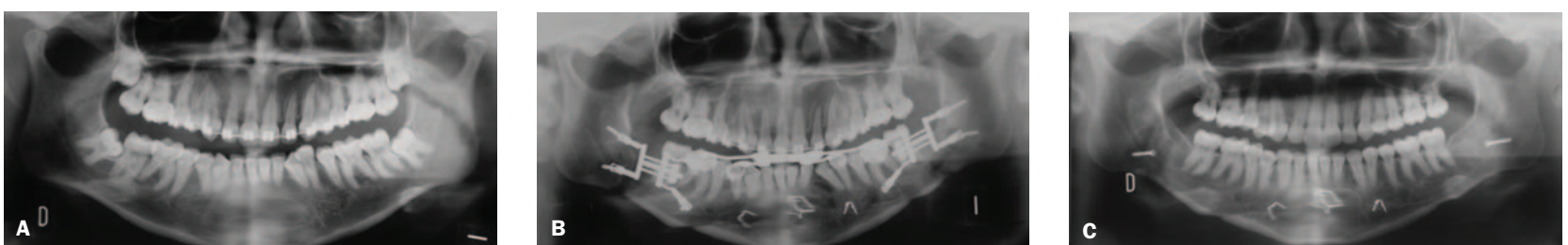


FIGURE 32-8 Panoramic radiograph sequence. A, Six months before surgery, when the third molars were removed. B, After complete activation of the devices. Observe the radiolucent distraction site between the left lateral incisor and the canine and proximal to the second molars. The screws are placed with some inclination to avoid damage to the inferior alveolar nerve and dental roots. C, Four years after distraction. Note that the posterior-inferior screws were left in place to avoid wound reopening, as explained in Figure 32-7C.

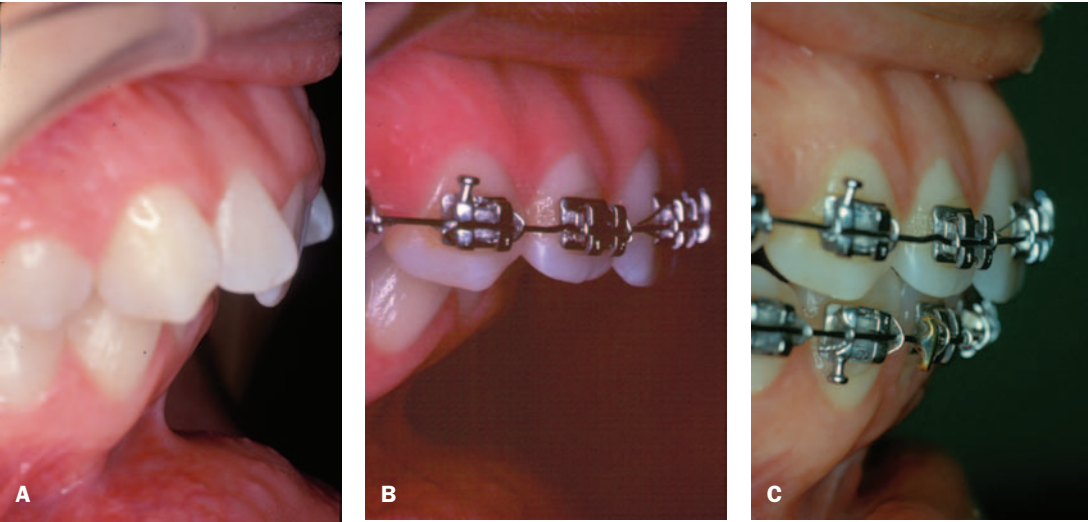


FIGURE 32-9 Dental profile view sequence. A, Preoperatively. B, After presurgical orthodontic treatment with adequate maxillary arch alignment and correct SN-1 angulation. Note the overjet increase. C, After mandibular widening and lengthening were performed and postsurgical orthodontics were finalized.



FIGURE 32-10 A–C, Initial dental views. Class II, division 2; observe the retroclined maxillary incisors increasing the overbite and decreasing the overjet. D–F, Presurgical orthodontic treatment to align the upper arch and increase the overjet. Regarding the mandibular widening, the occlusogram study revealed that simultaneous maxillary expansion was not necessary. G–I, Finalizing orthodontic treatment after simultaneous mandibular widening and lengthening were performed. J–L, Four years after orthodontic appliance removal.

elastics) but also laterally and exerting very detrimental forces to the TMJ, causing pain, dysfunction, and damage to the joints (Figure 32-11). There is lateral torque force against the condyle, loosening of the screws, and bending of the appliance as the muscle forces bend the device.

Mandibular advancement needs to be planned in such a way that the distal segment is transported anteriorly into an ideal Class I occlusion, counteraffecting the reciprocal forces of the advancement with heavy Class II elastics (6 ounces per side), without any lateral or medial condylar repositioning. All of these unfortunate situations are to be avoided by proper planning and meticulous surgical-orthodontic execution.

For bilateral mandibular lengthening, the right appliance must be parallel to the left one. If the occlusion is unstable when the activation period is finished, occlusal masticatory forces will cause instability in the appliance, movement of the distraction chamber, and weakening of the callus; consequently, the surgeon will need to graft and use heavy, rigid fixation.

The orthodontist's role is paramount, from the proper and complete diagnosis to the postsurgical orthodontics, preparing the dentition for surgery, helping in the surgery planning, adjusting the occlusion just after surgery, finalizing the dental interdigitation, analyzing the functional outcome, and following the retention period.

Many patients will require dental multispecialty work, and the orthodontist handles the reference of the patient and the treatment sequence.

Surgical Procedure

Incision and Exposure. A 2.5 cm full-thickness incision is made over the external oblique line, extending inferiorly over the alveolar ridge to the position of the first molar. Meticulous subperiosteal tunneling dissection is performed using a periosteal elevator to expose the alveolar ridge and the buccal cortex down to the inferior border of the mandible between the second and third molars, where a small channel retractor is placed to protect the soft tissues during the osteotomy. The periosteum, muscles, and soft tissues are minimally detached, maintaining the best blood supply possible to the area.

Osteotomy. With the channel retractor in position, a reciprocating saw is used to section the inferior border of the mandible bicortically at a 45° angle to increase the bony surfaces, up to around 3 mm away from the inferior alveolar nerve, continuing only on the lateral mandibular cortex superiorly (Figure 32-12). A periosteal

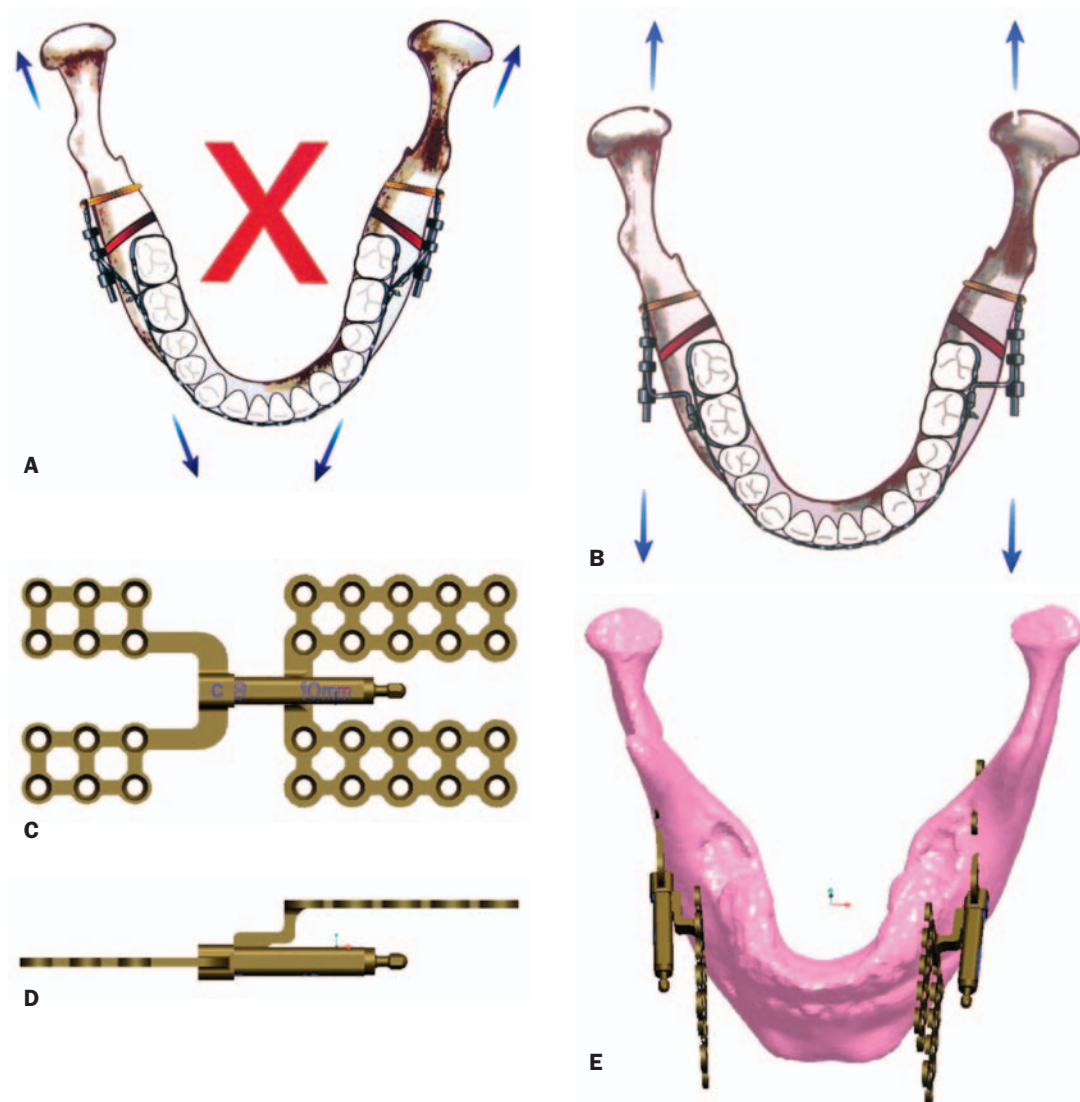


FIGURE 32-11 Importance of distractor parallelism in the axial plane. A, Incorrect distraction vector, in which both distractors are placed toward the midline. The reciprocal forces exerted to the mandible by the appliance as it is activated will advance the mandible, moving the proximal segments posterior and laterally, causing detrimental forces to the temporomandibular joint, with pain, dysfunction, and damage to the joints. B, Observe the anterior arms of the distractors bent in a step fashion to achieve the proper vector. The appliance screws are positioned parallel to each other in the axial plane, avoiding lateral displacement of the proximal segments. Only posterior displacement is presented and is compensated by the use of heavy Class II elastics during the activation and consolidation periods. C, New distractor prototype with two anterior and two posterior meshes for transmucosal fixation and a central activation rod. D and E, The anterior fixation meshes are bent to achieve parallelism in the axial plane for an adequate distraction vector.

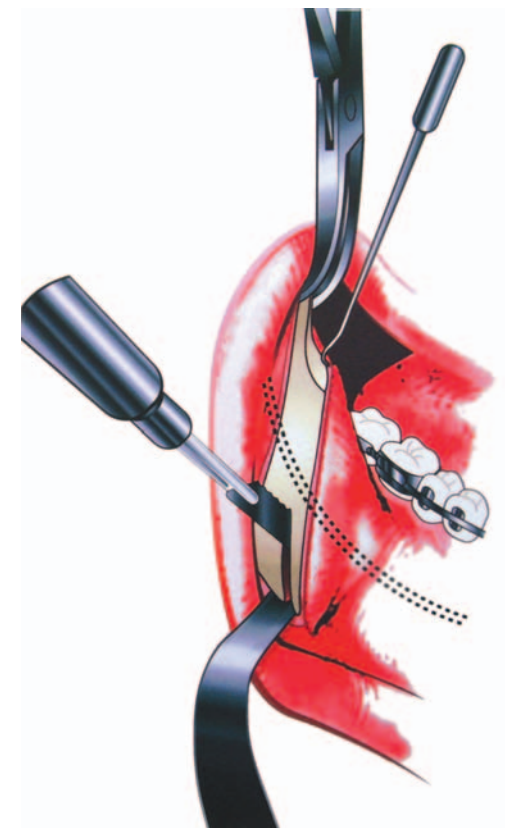


FIGURE 32-12 After incision and tunneling dissection, a channel retractor, a Kocher tissue forceps and a skin hook are placed to protect the soft tissues while the reciprocating saw is used bicortically in a 45° angle under abundant irrigation to section the inferior border of the mandible up to 3 mm away from the alveolar nerve.

elevator is placed between the lingual soft tissues and the mandible to guard against lingual nerve injuries while the alveolar area is sectioned bicortically from the top toward the inferior alveolar nerve area 3 or 4 mm short, with the saw upside down and at a 45° angle (Figure 32-13). Abundant irrigation is used throughout the osteotomy to avoid bone overheating. At this point, the uncut bone is just 6 mm around the mandibular nerve; the inferior, superior, and lateral cortices have been osteotomized, but the mandible is still rigid.

To preserve the dental follicles and the inferior alveolar nerve during the osteotomy, lateral and anterior-posterior cephalic radiographs are used to measure the distance between them and the inferior border of the mandible to avoid magnifications that might interfere with exact surgical planning, producing injuries to nerves or teeth.

The osteotomy is performed 3 mm posteriorly to the second molar root to avoid surgical damage or tooth devitalization. Third molars

should be removed 6 months prior to the distraction procedure; this would allow healing of the socket to improve bone stock for distraction, also avoiding saliva and food entrance into the distraction site.

Soft Tissue Closure. The distractors are measured, bent, and adapted over the dental or three-dimensional models before surgery, and only minor adjustments are usually necessary to position the device at the time of surgery.

Before completing the osteotomy, the muco-periosteal flap is repositioned and maintained in place by horizontal mattress sutures, leaving a small opening at the top of the incision. The distractors are fixated transmucosally over the mandible with bicortical screws; the anterior superior arm might be fixed with a 0.024-inch gauge wire around the teeth and acrylic to make it rigid (Figure 32-14).

Mobilization of the Segments and Activation of the Device. Once the distractor is well fixated

with bicortical screws, the appliance is activated 2 mm to create tension on the incomplete fracture line and a chisel is used between the proximal and distal segments at the superior border of the mandible, through the small incision left open. A torque movement is applied to the chisel to complete the mandibular osteotomy (Figure 32-15).

Once the bone fragments are separated with the chisel, a single mattress suture is placed to close the remnant of the wound; this maneuver ensures primary closure over the osteotomy, eliminating distraction chamber contamination and offering periosteum integrity.

When both sides are to be operated on, final sectioning of the ramus is deferred until the osteotomy of the opposite side is completed.

Distraction Protocol

After surgery, a 7-day latency period is awaited for collagen type I fibers to develop, primary soft tissue to heal, and initial surgical edema to reduce. Activation follows at a rate of 1 mm once a day until the desired distraction is completed; while the patient is activating the distractors, close monitoring should take place to avoid midline deviations owing to inadequate counterclockwise or uneven activation of the distraction devices. If needed, asymmetric activation should be done to correct maxillomandibular midline discrepancy.

An important issue is the TMJ. While the device is being activated, there will be reciprocal forces against the glenoid fossa, causing flattening of the condylar cartilage layer, thinning and perforation of the disk, subchondral bone formation, and loss of supra- and inframeniscal spaces, as shown in condyles histology of baboons after mandibular lengthening^{14,15} (Figure 32-16A to 32-16C).¹⁰⁻¹³ It is fundamental to unload the joints as we are advancing the mandible. The presurgical orthodontic phase includes rectangular surgical orthodontic arches with welded vertical pins to apply Class II elastics,

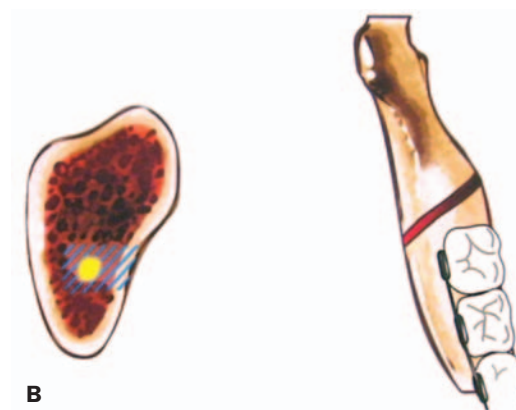
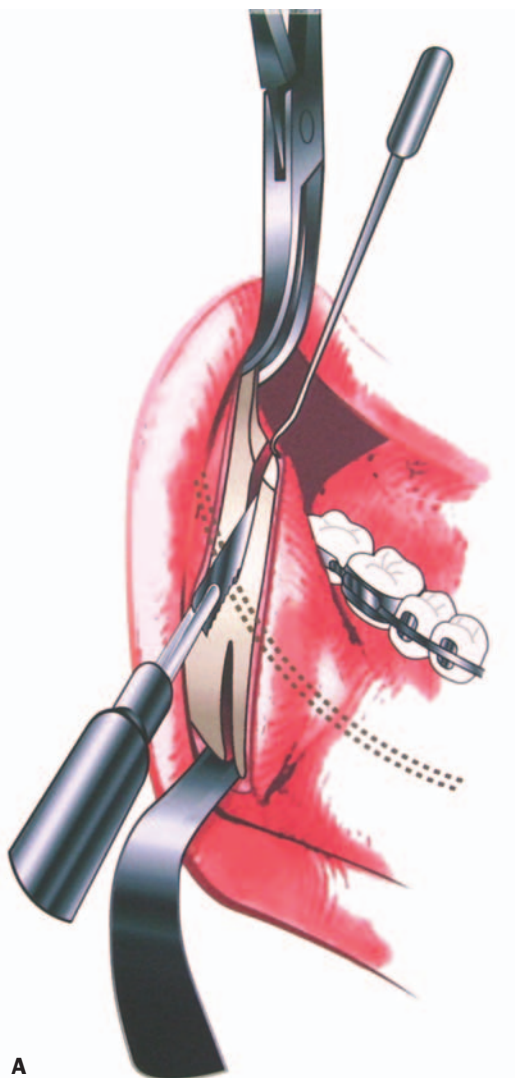


FIGURE 32-13 A, A Kocher tissue forceps and a skin hook are placed to protect the soft tissues; a periosteal elevator could also be used between the mandible and lingual soft tissues to guard against lingual nerve injuries while the alveolar area is sectioned bicortically from the top toward the inferior alveolar nerve area 3 or 4 mm short. B, The osteotomy is performed in a 45° angle to increase the bony surface for distraction. The buccal cortex is also osteotomized, leaving only 6 mm of bone continuity around the mandibular nerve.

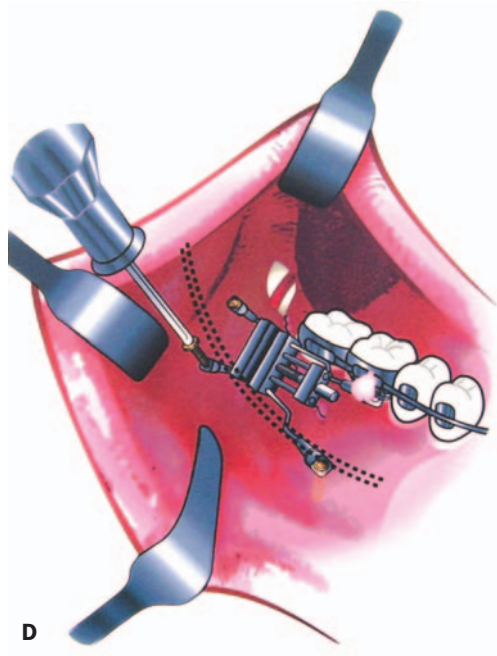
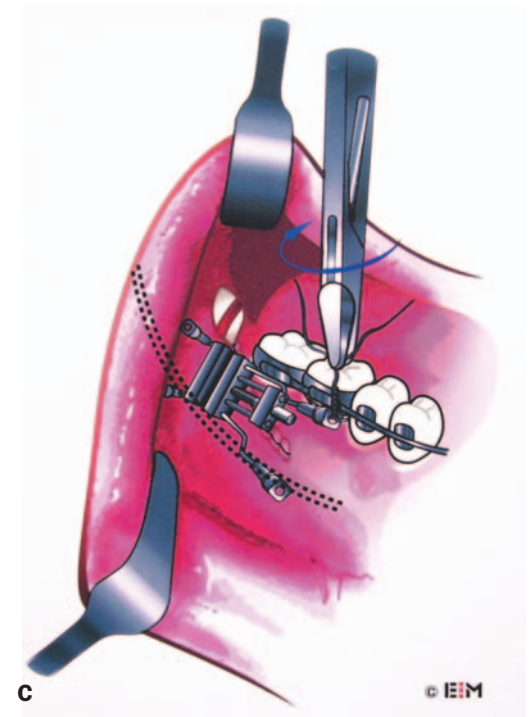


FIGURE 32-14 A and B, Before completing the osteotomy, wound closure is carried out, leaving a small opening in the superior portion. C–E, The distractor is fixated transmucosally using a 0.024-inch gauge wire for the anterior-upper arm and bicortical screws for the other arms, avoiding teeth roots and the alveolar nerve.

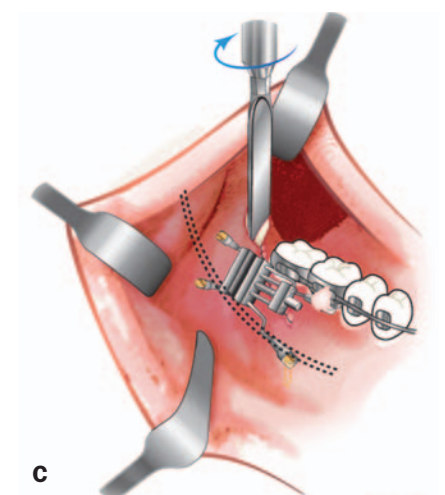
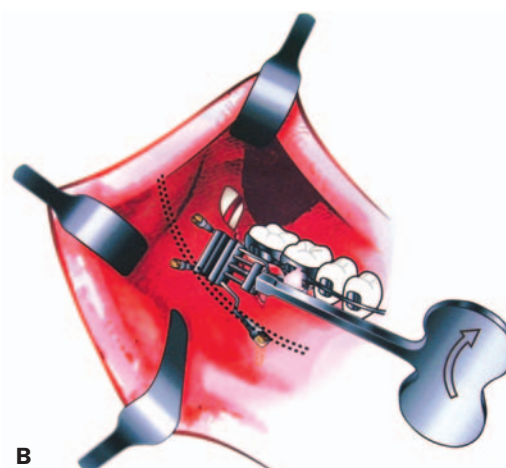
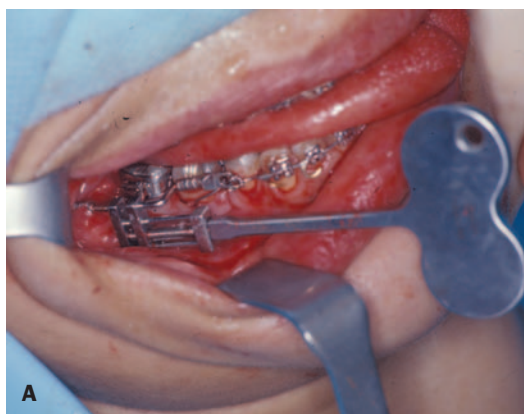


FIGURE 32-15 A and B, The appliances are activated to create tension on the incomplete fracture line. C, A chisel is used between the proximal and distal segments through the small incision left open, and a torque movement is applied to complete the mandibular osteotomy.

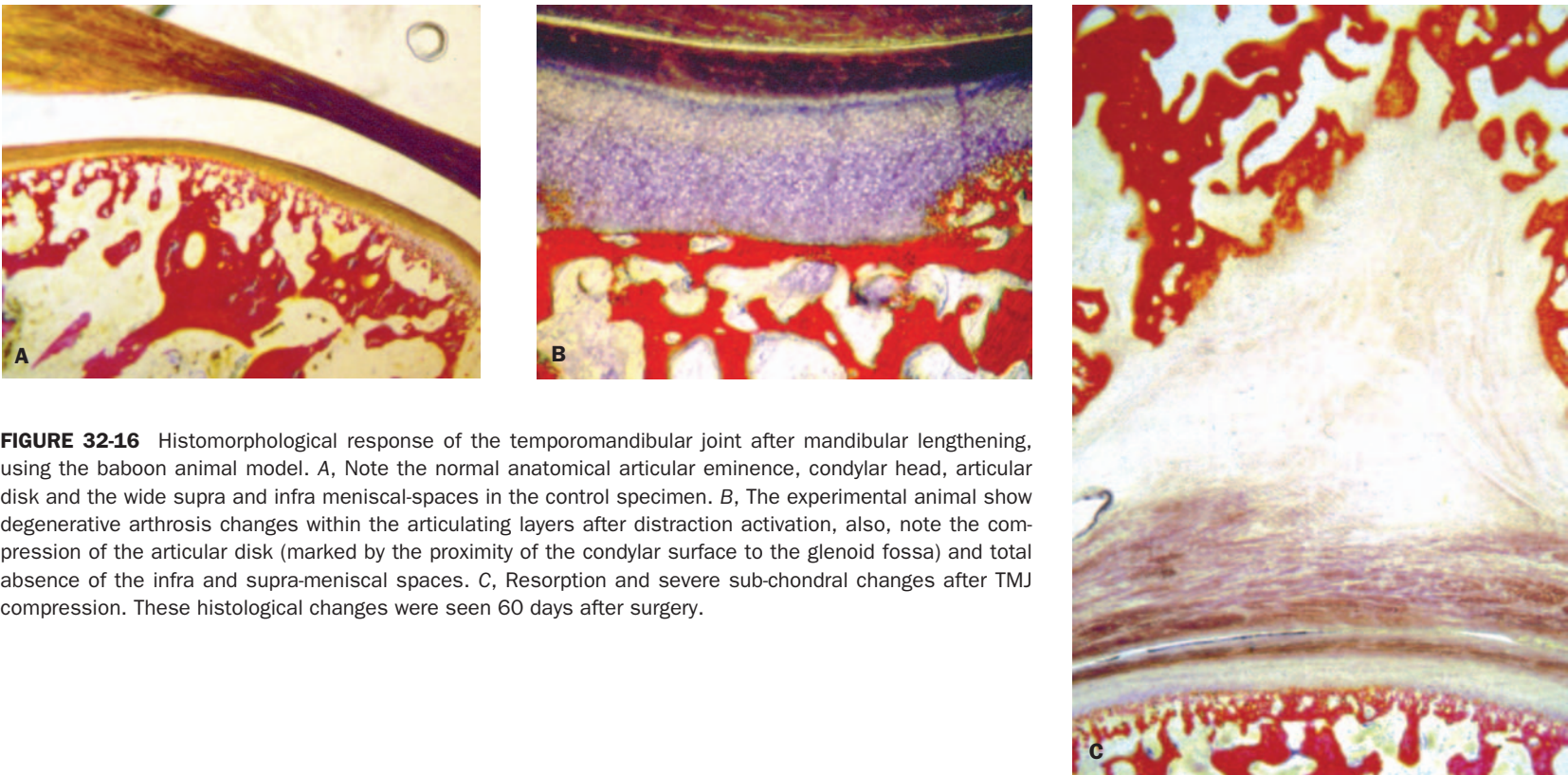


FIGURE 32-16 Histomorphological response of the temporomandibular joint after mandibular lengthening, using the baboon animal model. *A*, Note the normal anatomical articular eminence, condylar head, articular disk and the wide supra and infra meniscal-spaces in the control specimen. *B*, The experimental animal show degenerative arthrosis changes within the articulating layers after distraction activation, also, note the compression of the articular disk (marked by the proximity of the condylar surface to the glenoid fossa) and total absence of the infra and supra-meniscal spaces. *C*, Resorption and severe sub-chondral changes after TMJ compression. These histological changes were seen 60 days after surgery.

6 ounces per side, during the distraction and consolidation periods to unload the TMJs (Figures 32-17 through 32-20).¹ Poorly monitored Class II

elastics may contribute to inadequate correction of the Class II malocclusion, requiring a secondary surgical procedure.

Children with first dentition requiring mandibular lengthening need Erich arch bars during surgery for Class II elastic placement



FIGURE 32-17 *A*, Profile view of a 21-year-old female with anterior-posterior maxillary excess combined with anterior-posterior mandibular deficiency and temporomandibular joint degenerative disease. *B*, Profile view 3 years after mandibular lengthening and advancement genioplasty. Premolar extractions were carried out before presurgical orthodontic preparation. *C* and *D*, Frontal full-face view preoperatively and 3 years later.

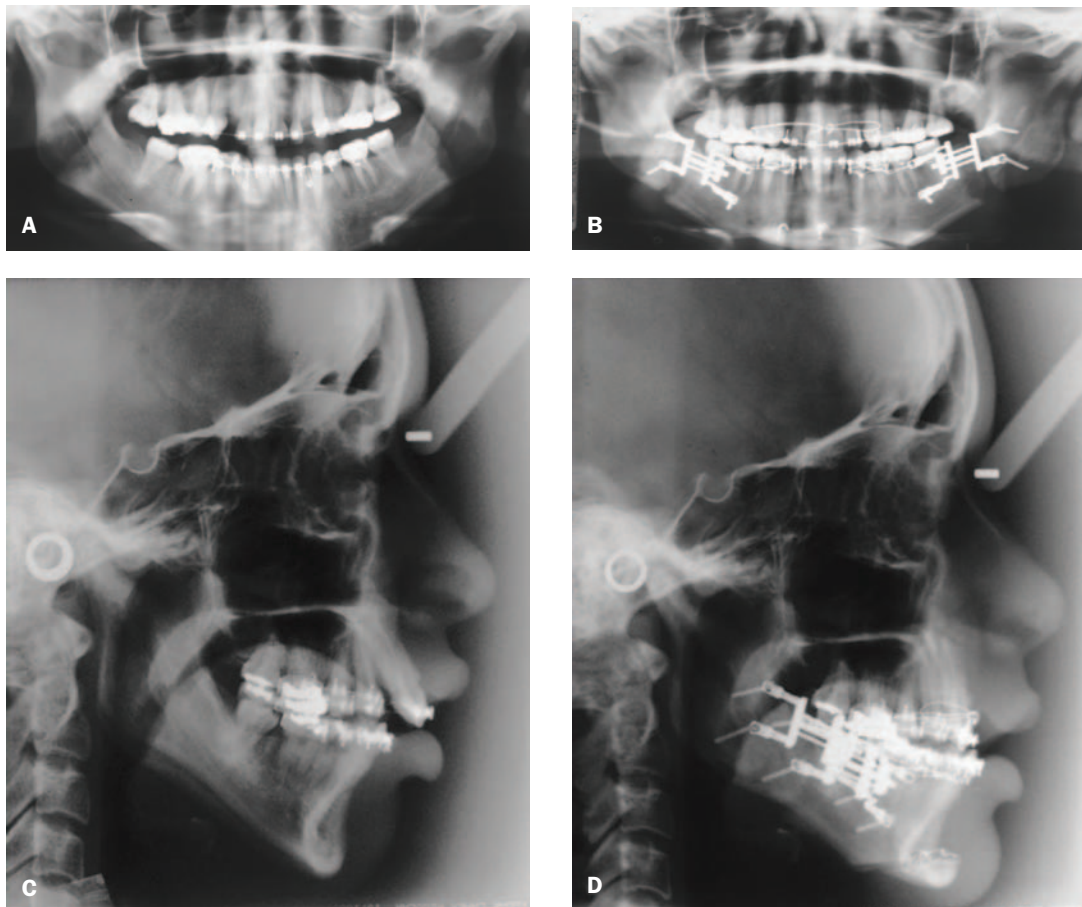


FIGURE 32-18 A, Panoramic radiograph after premolar extractions and presurgical orthodontics. Spaces left by the premolars were closed, leaving small diastemas between the upper lateral incisors and the canines. Observe the condyle shape. B, Panoramic radiograph after the activation phase was completed. An anterior maxillary osteotomy was also performed to close the diastemas and the open bite, also improving the SN-1 angle. C, Presurgical lateral cephalic radiograph after orthodontic preparation was accomplished. D, Postactivation lateral cephalic radiograph with distractors parallel to the occlusal plane. Chin advancement and anterior maxillary osteotomy are also evident.

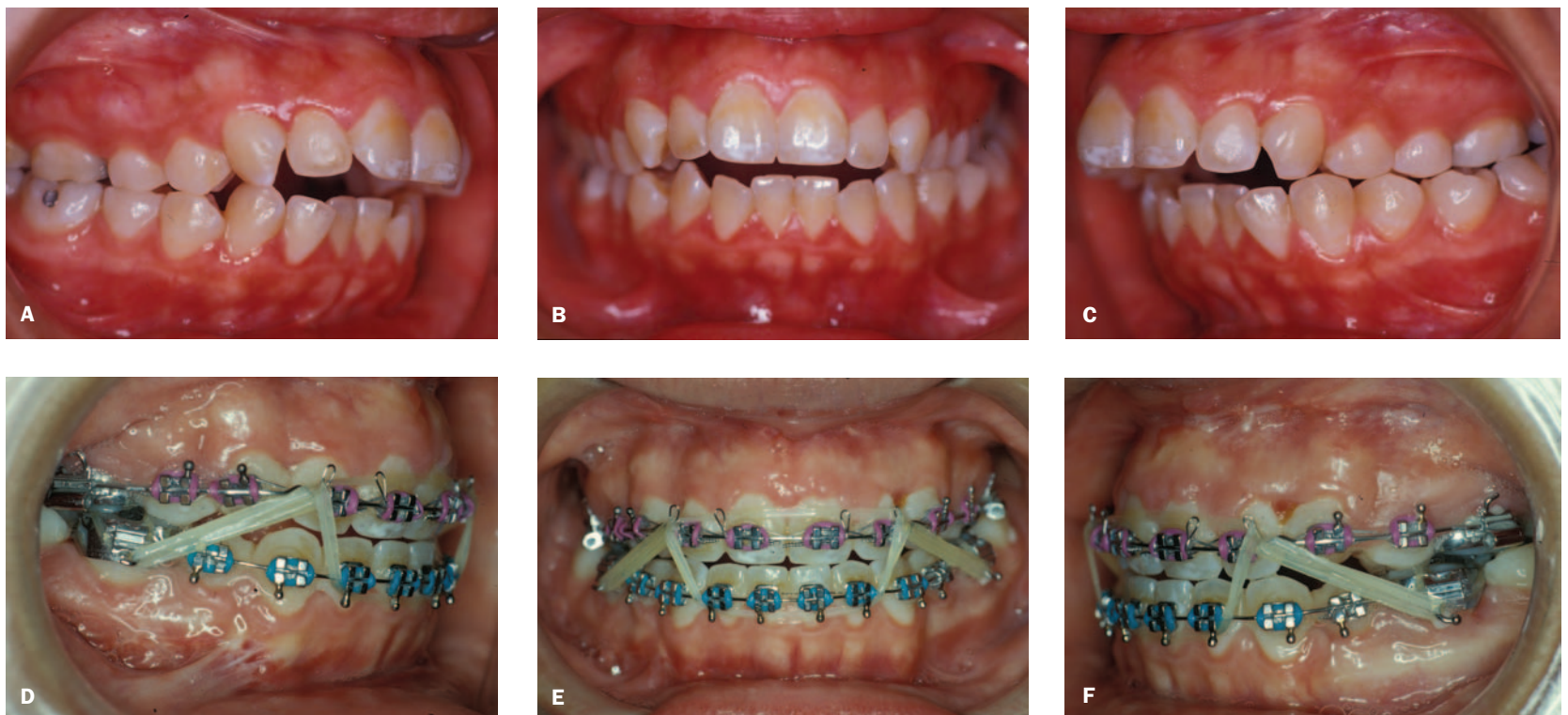


FIGURE 32-19 A–C, Initial dental views. Class II, division 1 malocclusion. The inferior midline is deviated to the left. D–F, An intraoral view after complete activation was achieved. Class II elastics are worn during the activation and consolidation periods to unload the jaws. The midline was corrected by asymmetric activation of the appliances.



FIGURE 32-19 continued. G–I, Occlusion 3 years later, with coincident upper and lower midlines and adequate dental interdigitation.

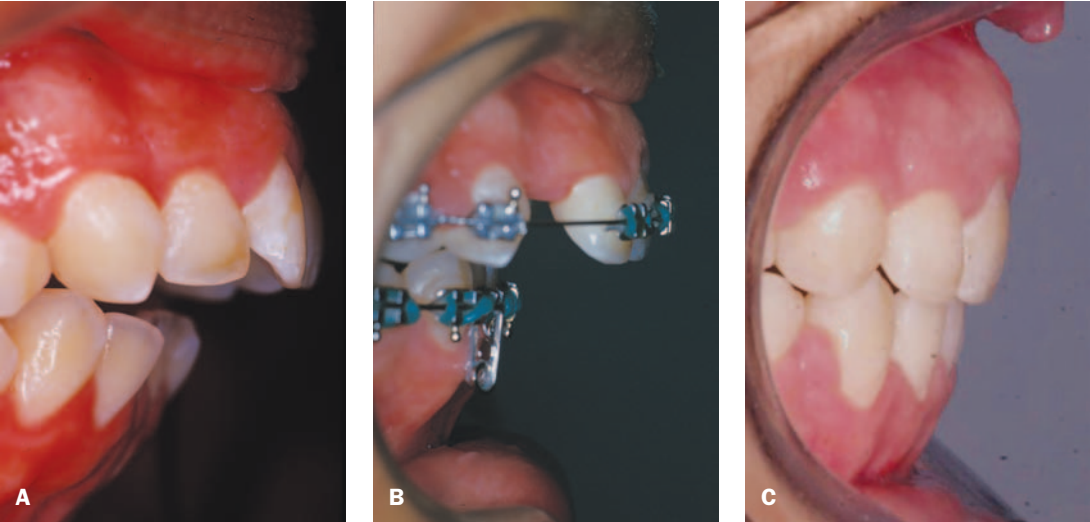


FIGURE 32-20 Lateral intraoral view sequence. A, Before treatment. B, After premolar extractions and orthodontic preparation. Note the diastemas between lateral incisors and canines. C, Three years postoperatively.

through the activation and consolidation phases and postsurgical occlusion control (Figures 32-21 through 32-28).

After total activation is accomplished, acrylic is placed over the distraction’s rod for stabilization purposes and the appliances are used throughout the consolidation period as a fixation system. Radiographs are taken to verify the

distraction chamber ossification for appliance removal.

A liquid diet, including high-protein supplements, is recommended during the activation period, followed by a soft diet once the distractor is stabilized with acrylic until consolidation is achieved, approximately at the eighth postoperative week.

Management of Open Bites Developed during Mandibular Lengthening

An anterior open bite might develop during the activation of the appliances because of inadequate parallelism between the occlusal plane and the distractor rod or preexisting skeletal open bites. To correct this problem, the wire around the first

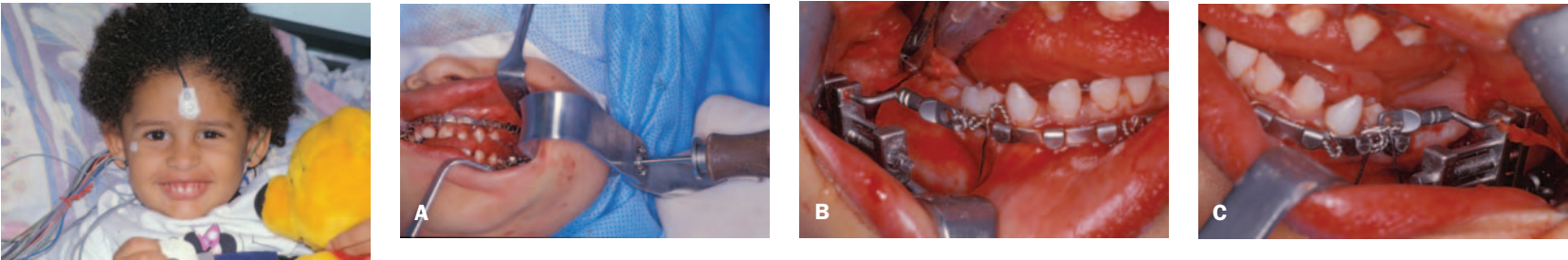


FIGURE 32-21 Polysomnography was used to diagnose sleep apnea in a 2-year-old patient.

FIGURE 32-22 A, Intraoperative photograph. A transcutaneous trocar was used to facilitate screw placement. B and C, Dental Erich arch bars are placed to control the occlusion in patients with primary dentition. Observe the appliances in position.

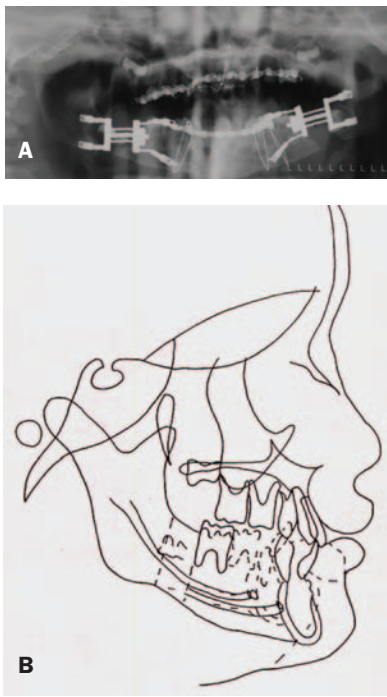


FIGURE 32-23 A, Panoramic radiographs after complete distractor activation. Observe the circummandibular wires and piriform rim suspension used to enhance Erich arch bar fixation. B, Pre- and postoperative tracings. Observe the changes after mandibular lengthening to correct the sleep apnea.

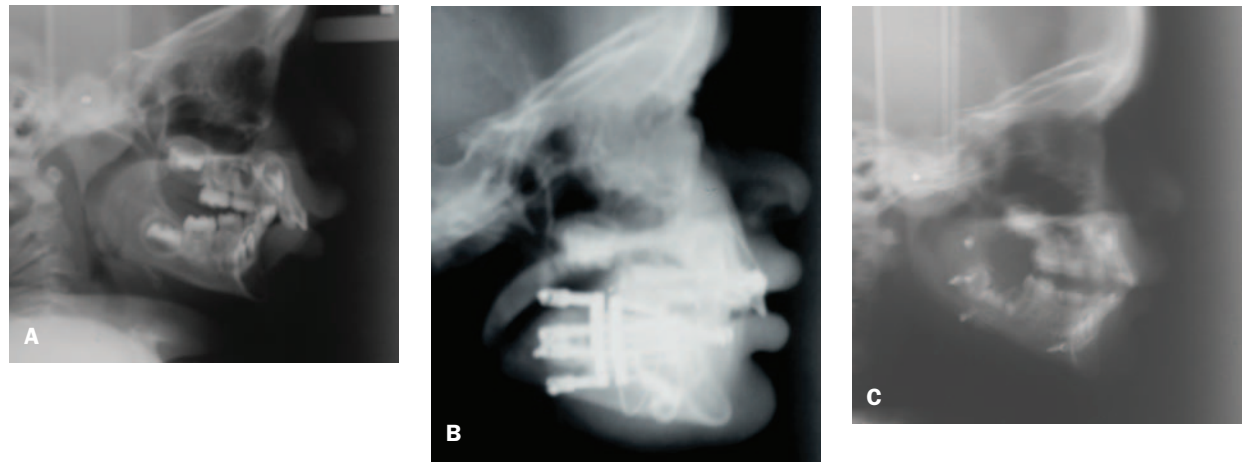


FIGURE 32-24 Lateral cephalic radiograph sequence. Preoperatively, with the distractors parallel to the occlusal plane, and after consolidation, when the distractors were removed.



FIGURE 32-25 Right dental view sequence. A, Erich arch bars are used for Class II elastics during the activation and consolidation periods. B, Observe the total mandibular advancement. C, Eight years later. Mixed dentition is now observed.

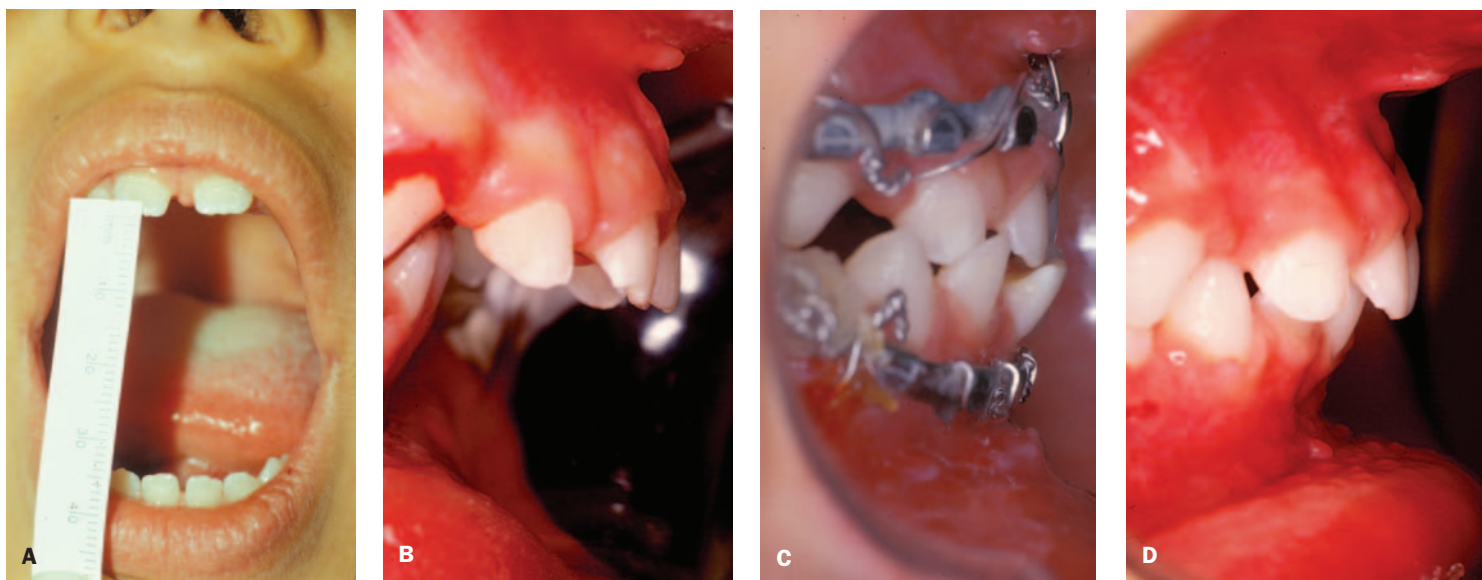


FIGURE 32-26 A, Conserved mouth opening after mandibular lengthening. B-D, Lateral dental view sequence before surgery, after the activation period, and 8 years after mandibular lengthening.



FIGURE 32-27 Complete facial sequence pretreatment, after mandibular lengthening, and at the 6- and 8-year follow-ups.



FIGURE 32-28 A, Observe the severe mandibular hypoplasia in the preoperative profile. B–D, Profile view sequence after mandibular lengthening, 6 and 8 years later. Observe the harmonious facial and mandibular growth.

or second molar to fixate the distractor’s anterior arm is removed and replaced by another wire placed in an anterior position, allowing the distal mandibular segment to rotate in a counterclockwise manner to close the anterior open bite. This should be done under intravenous sedation and local anesthesia with the surgeon’s manual

guidance. The new 0.024-inch gauge wire is secured with dental resin or quick-setting acrylic. Lateral cephalic radiographs are essential to plan and reevaluate the situation. The distraction appliance should remain in place until the consolidation period elapses, demonstrating the disappearance of the fibrous

interzone in radiographs. This mid-distraction chamber is the last to mineralize, and early removal of the device would cause movement at that site, requiring heavy rigid fixation and bone grafting. Leaving the segments to heal spontaneously with the teeth wired together will allow proximal fragment anterior and superior

rotation, with loss of mandibular angle projection or even malunion in large movements.

Considerations

- The distractors are rigidly fixated with bicortical screws, avoiding teeth and the alveolar nerve; when a bicortical screw could not be placed without damaging the dental structures, a 0.024-inch gauge wire could be used to fixate the distractor.

A transcutaneous trocar could be used to place the distractor's posterior screws, especially in small children, patients with tiny oral commissures, or where the vertical osteotomy is located too far posteriorly (see Figure 32-22).

There are two basic designs for the osteotomy in mandibular lengthening by distraction osteogenesis: a 45° angle osteotomy (see Figure 32-13) or a standard sagittal split of the ramus. It is beyond the scope of this chapter to discuss the benefits and risks of inferior alveolar nerve damage, comparing one design versus the other; however, the anatomy of the area varies greatly, making it difficult to complete a sagittal split osteotomy. In other situations in which major advancement is planned and nerve stretching could overpass the nerve distention capacity, a sagittal split osteotomy for distraction would offer an unlimited amount of mandibular lengthening without damaging the nerve.

Fixating the appliances transmucosally, after suturing the mucosa, offers a closed distraction chamber, avoiding infection or weak callus formation, for a predictable, full bony regeneration. When it is not possible to place the distractor transmucosally, the appliance is fixated to the bone with the wound open and every effort is made to perform a watertight closure around the arms of the distractor, which is especially difficult in the medial aspect of the device. In these cases, the wound needs to be reopened for distractor removal after the consolidation period.

Patients with hemicraniofacial microsomia, Treacher Collins syndrome, and Pierre Robin sequence may present with minimal bone stock in the post molar and angle regions, compromising the distraction regenerate. In these cases, it is advisable to plan the surgery along the body of the mandible between the premolars or the premolars and molars, where a better bone situation is usually encountered; the possibility of performing the osteotomy anterior to the mental nerve eliminates any chance of paresthesia. The inadequate ramus anatomy is left intact, avoiding poor bone healing, a long-term consolidation phase with the distractors in place, and the need for heavy rigid fixation to warrant stability after appliance removal (Figures 32-29 through 32-34).



FIGURE 32-29 Treacher Collins syndrome and Pierre Robin sequence in an 18-year-old female. A and B, Profile views preoperatively and after mandibular lengthening with combined genioplasty was conducted. Mandibular lengthening of 24 mm at the inferior border of the mandible and 12 mm chin advancement for a total of 36 mm mandibular anterior movement. A maxillary widening was also included in the same surgical procedure. C and D, Frontal facial views before and after mandibular lengthening, chin advancement, and maxillary widening were accomplished. Observe the chin vertical augmentation achieved.

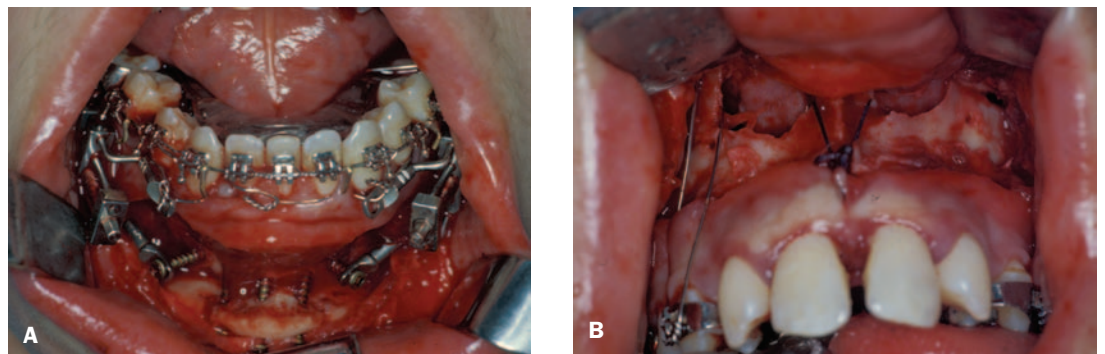


FIGURE 32-30 Surgical procedure. A, Chin advancement and distractors fixated. B, Midline maxillary widening.

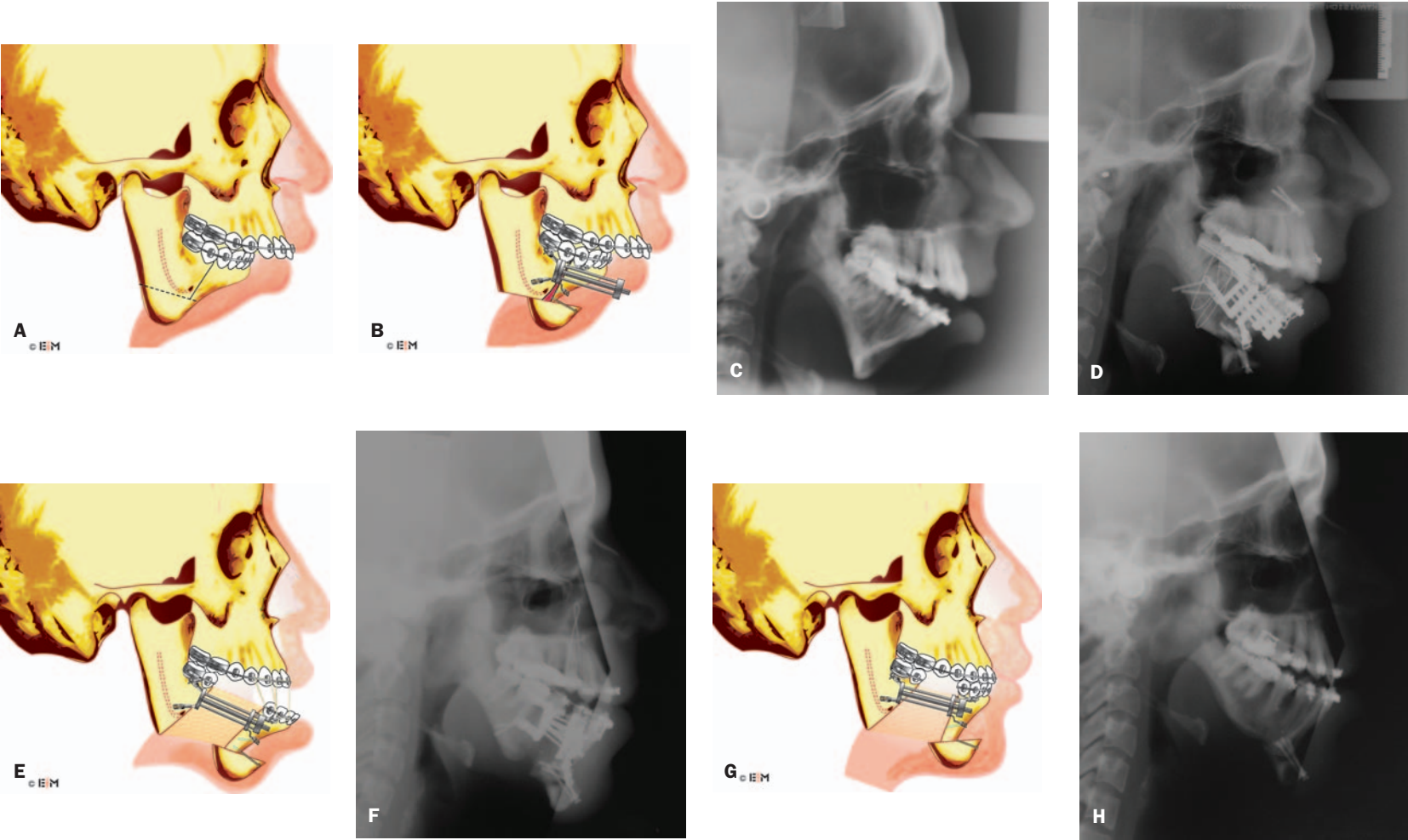


FIGURE 32-31 A and B, The osteotomy site was planned between the inferior premolars, where a better bone source was encountered. A genioplasty was also considered. C, Preoperative lateral cephalic radiograph. Observe the inadequate anatomy for sagittal split osteotomy and the reduced bone quantity posterior to the second molar area, compromising distraction osteogenesis at this level. An anterior open bite is also evident. D, A genioplasty was performed, along with mandibular lengthening between the premolars and midmaxillary widening. The distractors were placed parallel to the occlusal plane, and as activation was carried out, the open bite worsened. E–G, To correct the open bite, the wire around the first premolar fixating the distractor’s anterior arm was removed and replaced by another wire placed in an anterior position, allowing the distal mandibular segment to rotate in a counterclockwise manner to close the anterior open bite under the surgeon’s manual guidance. H, Lateral cephalic radiograph after consolidation and appliance removal. Observe the increase in the distance between the pogonion and the hyoid bone compared with the initial lateral cephalic radiograph.

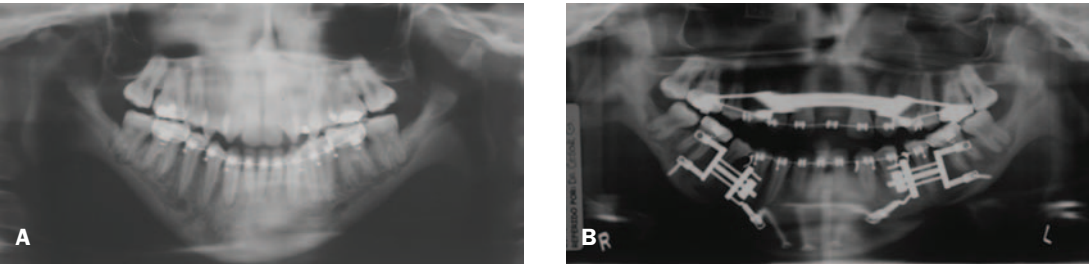


FIGURE 32-32 A, Preoperative panoramic radiograph. Note the reduced vertical high posterior to the second molar area. B, Panoramic radiograph after activation for mandibular lengthening and maxillary widening were completed. Observe the radiolucent distraction sites at the inferior border of the mandible between the premolars and at the maxillary midline, where a plastic tooth was placed.

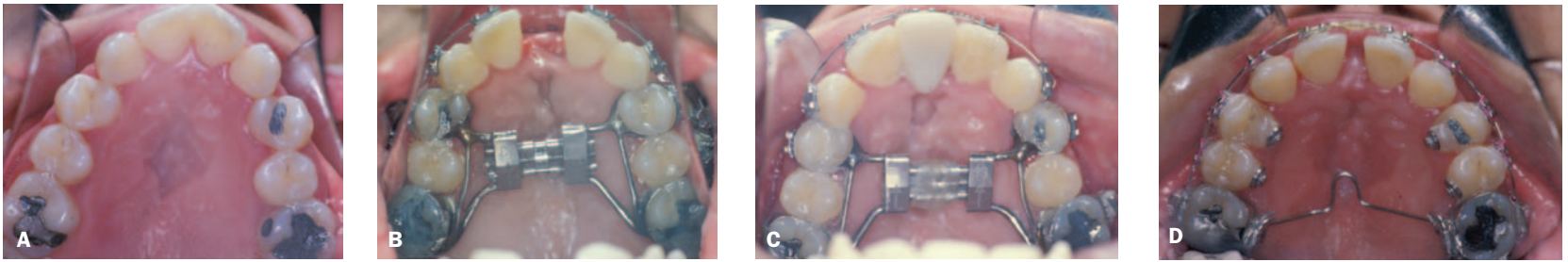


FIGURE 32-33 Maxillary occlusal view sequence. A, Preoperatively. Note that upper lateral incisors are congenitally missed. The cleft palate was closed at 18 months of age. B and C, After complete device activation, a plastic tooth is placed to keep the teeth from “walking” too fast into the distraction chamber as the transseptal fibers stretch. D, Eight weeks after activation is completed, the dental pontic is reduced 1 mm on each side every month, and the gap is progressively closed by the orthodontist.

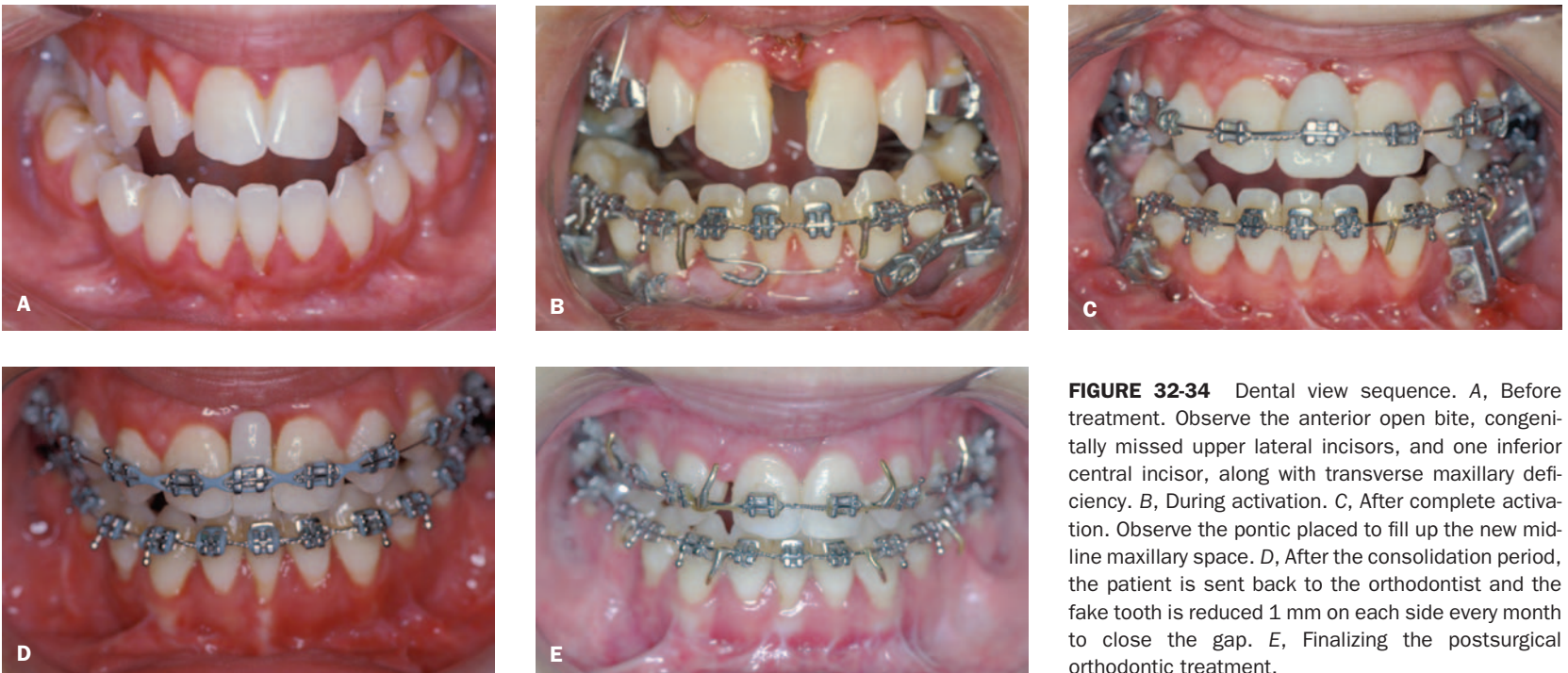


FIGURE 32-34 Dental view sequence. A, Before treatment. Observe the anterior open bite, congenitally missed upper lateral incisors, and one inferior central incisor, along with transverse maxillary deficiency. B, During activation. C, After complete activation. Observe the pontic placed to fill up the new midline maxillary space. D, After the consolidation period, the patient is sent back to the orthodontist and the fake tooth is reduced 1 mm on each side every month to close the gap. E, Finalizing the postsurgical orthodontic treatment.

Postoperative Considerations

The distractors should be removed after proper ossification has occurred, confirmed by a radiographic evaluation, considering the different variables involved in the healing process, such as the age of the patient, amount of movement, quality and quantity of bone, infection, inadequate stability during consolidation, poor patient selection, and some systemic diseases.

If the clinician removes the appliances before adequate bone ossification, perimandibular muscles will force the segments away from the planned repositioning, with the consequent development of an open bite, anterior mandibular ramus rotation (proximal fragment counterclockwise rotation), disappearance of the mandibular angle

projection, and TMJ pain and dysfunction. The use of maxillomandibular elastics to close the open bite is not indicated because extrude the superior incisors, the anterior open bite will relapse and prolong the postsurgical orthodontics, and the final occlusion will be unstable, heading for relapse and TMJ dysfunction symptoms.

Once the proper stabilization period has elapsed, usually 60 days for every centimeter of lengthening, the distractor is removed. Ideally, a second surgical procedure is not required; the wire around the crown of the first or second molar is cut and pulled out, and the transmucosal screws are removed. In the event of a submerged screw, a small incision is made to discover the screw.

Conclusions

Intraoral distraction osteogenesis allows mandibular lengthening with meticulous occlusal finishing, in a predictable and stable manner; maintaining the TMJs intact and conserving the preoperative anatomic characteristics.¹⁴⁻¹⁶ The surgical technique permits progressive augmentation of the hard and soft tissues, into an ideal dental occlusion. It is required that the orthodontist has prepared the dentition presurgically into an ideal arch situation and fixated the dental positioning with heavy rectangular arches to use intermaxillary heavy elastics, without individual tooth movement during the early postsurgical period but allowing complete joint unloading during the activation and consolidation phases.

The surgeon needs to have the possibility of changing the vector of fragment movement after surgery to secure an ideal occlusal relationship between the arches. The new internal appliances offer comfort, the possibility of lengthening asymmetric amounts, different lengths in the upper and lower mandibular body areas, and easier activation.

Distraction osteogenesis can produce ideal outcomes in many clinical situations in which traditional surgery offered limited results and failure. The possibility of lengthening the mandible in children and infants was limited before the application of Distraction Histogenesis. The need for advancing the mandible in older and arthritic joints patients were also a challenge for the clinician and major advancements were a reason for complications and relapse. This new technology is a must for every maxillofacial surgeon. The future of this subspecialty is in developing better appliances and bioengineering to enhance the healing process and shorten the whole surgical-orthodontic treatment.

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Logarithmic Distraction of the Mandible Using an Internal Curved Distractor

Stephen Schendel and Don W. Linck II

Distraction of the craniofacial skeleton is now an accepted technique in the reconstruction of craniofacial malformations. The original work of Gavriel Ilizarov provided the impetus for this subsequent experimental and clinical research on distraction osteogenesis.¹⁻⁶

The technique of long bone distraction has been discussed in the orthopedic surgery literature since the 1950s, and there is no question as to its effectiveness and ability to lengthen long bones.⁷

Snyder and colleagues were the first to report distraction of the mandible in dogs in 1973.⁸ This was followed in the early 1990s by the initial studies of mandibular distraction in humans by McCarthy and colleagues, who performed the procedure on craniofacial deformity patients.⁹⁻¹² Most of this work involved linear, external distractors that did not have the ability to distract in three planes of space. Later, the technique of mandibular lengthening by buried osteodistractors also essentially involved only straight-line distractors.^{13,14} Although straight-line distraction adequately lengthens the bone, most craniofacial bone lengthening requirements are nonlinear, and the aftereffects of linear distraction on the dental occlusion of the teeth leaves something to be desired. If the straight-line distractor is placed in the body of the mandible, then the end result is often a mandibular body that is lengthened, but the dental occlusion ends up with an anterior open bite.^{15,16} Extensive and long orthodontic treatment is then required. Although this is certainly something that can be accomplished, it is by no means something that is easy to do, and the end result can be compromised. When the straight-line distractor is placed in the ascending ramus, the resultant lengthening creates a posterior dental open bite and there is usually not enough anterior-posterior correction of the body of the mandible.

Most mandibular distraction osteogenesis is performed in the growing individual, but it is being done more frequently in adults.¹⁷

Research has also shown that the mandible grows in an archial fashion, which has been hypothesized to be along a logarithmic spiral.¹⁸⁻³⁶

Information on gnomonic growth was originally clarified by D'arcy W. Thompson, whose original work related to gnomonic growth of both animals and plants.³⁷ Gnomonic growth is defined as an object becoming larger while maintaining the same general shape during its growth and maturation process (Figure 33-1).

Ricketts explained the growth of the human mandible as being via an archial nature.^{35,36} He arrived at a phenomenon that he called "growth emanating from a polar grid" that had its center near the superior aspect of the pterygomandibular raphe. This logarithmic spiral or archial pattern of the mandible's growth was along the line from the anterior border of symphysis of the mandible through to an area of the mandible that was near the posterior point of Xi, defined as the centroid of the ascending ramus of the mandible, which closely approximates the inferior alveolar foramen, and near a point between the coronoid notch and head of the coronoid process (point of Murray) (Figure 33-2).

Moss, together with his colleagues, was at the same time defining his archial growth concept as being an arc of a logarithmic spiral that passed through the mental and inferior alveolar foramina and foramen ovale (Figure 33-3).^{22-29,34} He

attributed this arc of mandibular growth to a neurotrophically mediated mechanism. This concept was further modified by Enlow, who described the mandibular areas of bone resorption and

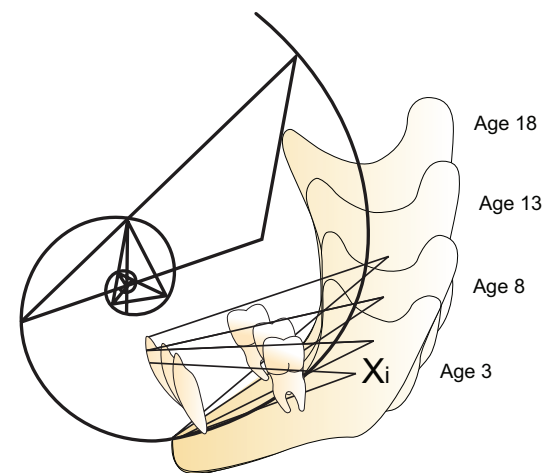


FIGURE 33-2 According to Ricketts, the mandible grows on an arc and the occlusal plane rises posteriorly with the Xi point.^{35,36} Note that this arc conforms very closely to the logarithmic spiral.



FIGURE 33-1 The classic example of a logarithmic spiral in nature is the shell of the giant Nautilus.

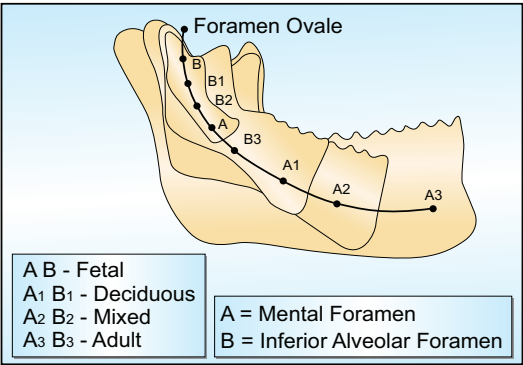


FIGURE 33-3 Moss’s research findings: superimposition of the foramen ovale indicates that all neural foramina at all ages fit precisely on the logarithmic spiral. 22–29,34

apposition as it was growing, so that the mandible would maintain its shape as a response to functional demands.¹⁹

It is through information of this nature that we derive the hypothesis that the mandible grows and develops in an archial fashion, and when doing so, eruption of the posterior teeth simultaneously occurs, maintaining dental occlusion while advancing the chin forward in space. It is through this mechanism that the occlusion remains stable while the individual bones of the face are growing.

In using this concept of logarithmic growth, a semi-buried distractor was designed that had curvilinear and spiral patterns, so that when placed in the area of the juncture of the ascending ramus and the corpus of the mandible (area of osteotomy), the archial path of distraction would mimic the logarithmic spiral of mandibular growth (Figure 33-4).^{38,39} This device has been tested in dogs, and the distraction process has

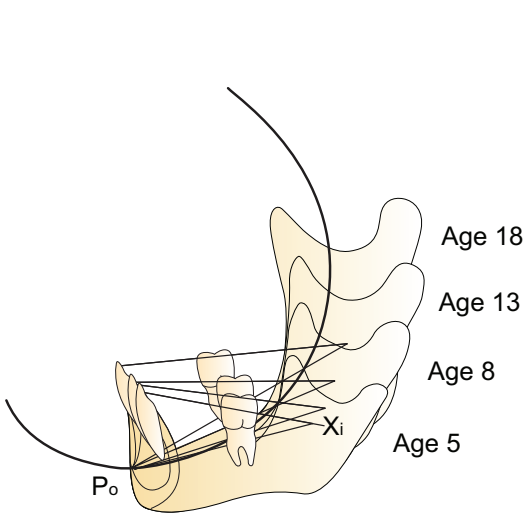


FIGURE 33-4 The archial nature of mandibular growth with elevation of the incisors and molars demonstrates how the occlusion compensates for mandibular growth.

been successfully achieved without complication.⁴⁰ Both groups achieved distraction lengths of 25 mm and 26 mm, respectively, which were stable on follow-up of 16 months. However, the internal spiral distractor resulted in a better postoperative occlusion and no open bites. Scarring and patient inconvenience were also reduced with this technique. Additionally, the internal technique may be combined with an Obwegeser sagittal split of the mandible, which permits rotation of the proximal segment and excellent bone mass.^{41,42} We have distracted up to 43 mm with this technique, without relapse.

The proper spiral is chosen by completing a visual treatment objective (VTO) based on the lateral cephalometric radiograph (Figure 33-5). The lateral cephalometric radiograph is first traced and an analysis performed. The position of the mandibular osteotomy site is then chosen and marked on the tracing. Generally, this is behind the last tooth and passes through the gonial angle region. If more vertical movement is desired, the cut is placed slightly above the gonial angle, and if more horizontal movement is required, the cut is placed at or in front of the gonial angle. The mandibular segment, with teeth in it, is then retraced in the desired occlusion.

The curvilinear motion to produce this mandibular movement can be found by Euclidean geometry, based on bisections of the lines connecting the osteotomy segments.⁴³ However, this movement usually produces insufficient descent and contour of the gonial angle region. (Remember that a straight-line distraction

produces even less posterior facial height and usually an open bite.) A template is used to pick the ideal spiral movement that will produce the desired mandibular form. The template consists of two spirals and four curved distractors (Figure 33-6). Recently, Nemotech has created a computerized cephalometric analysis system to perform this planning and accurately predict the end result of the distraction.

The distractor is placed via an intraoral incision into the mandibular ramus region, similar to a sagittal split incision (Figure 33-7). A subperiosteal dissection is undertaken, exposing the lateral mandible in the predetermined area of the osteotomy. Lingual dissections are also performed posteriorly to the lingular region. The osteotomy is marked as previously determined on the VTO. A corticotomy is then completed on the lateral mandible and medial ramus (anterior) to the lingula. A saw or drill may be used. The spiral distractor is then placed at its predetermined position. The distractor is fixed to the proximal mandibular segment by monocortical screws; 3 arms with 2 screw holes each are provided to allow flexibility in screw placement. Only 2 to 3 screws are necessary for retention on each side of the osteotomy. The osteotomy is next completed with an osteotome. Following this, the distal segment of the distractor is fixed with monocortical screws. A shim is placed at this time, if indicated. The activation screw may exit into the mouth or from the skin, depending on the distractor orientation (Figure 33-8). The incision is closed in a running fashion with a

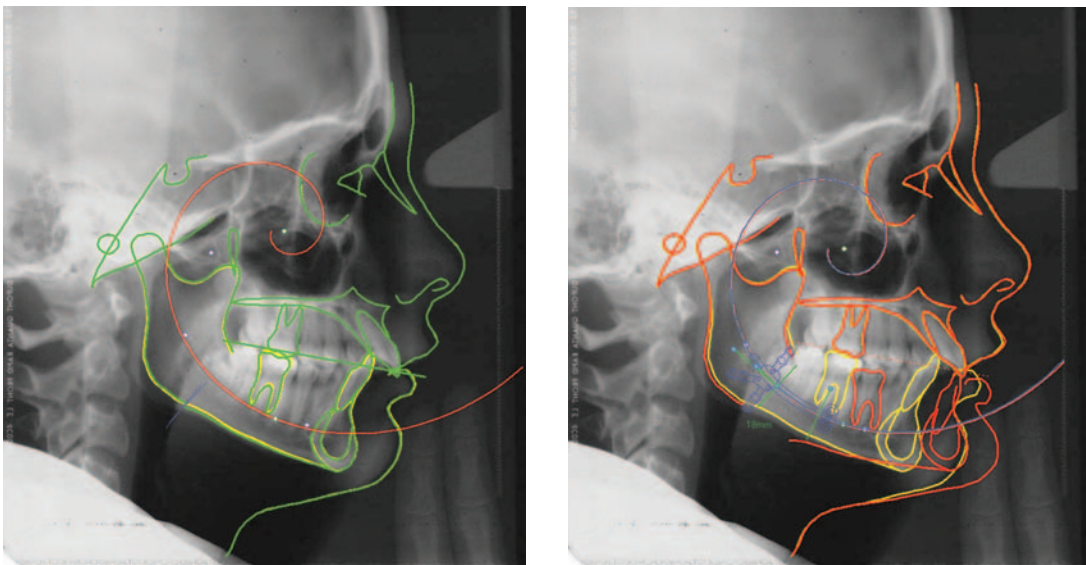


FIGURE 33-5 A visual treatment objective is done in order to choose the correct distractor to match the logarithmic spiral portion over the mandible to be distracted.

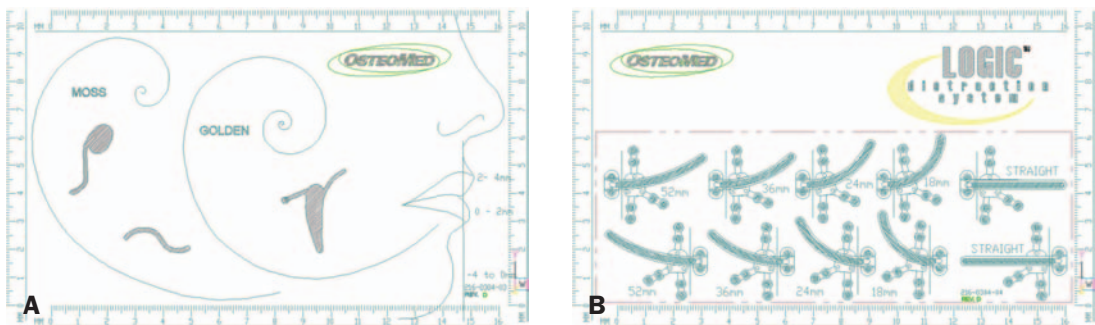


FIGURE 33-6 A, The spiral templates for placing the logarithmic spiral on the cephalometric tracing. B, The distractor templates to aid in choosing the correct distractor curve.

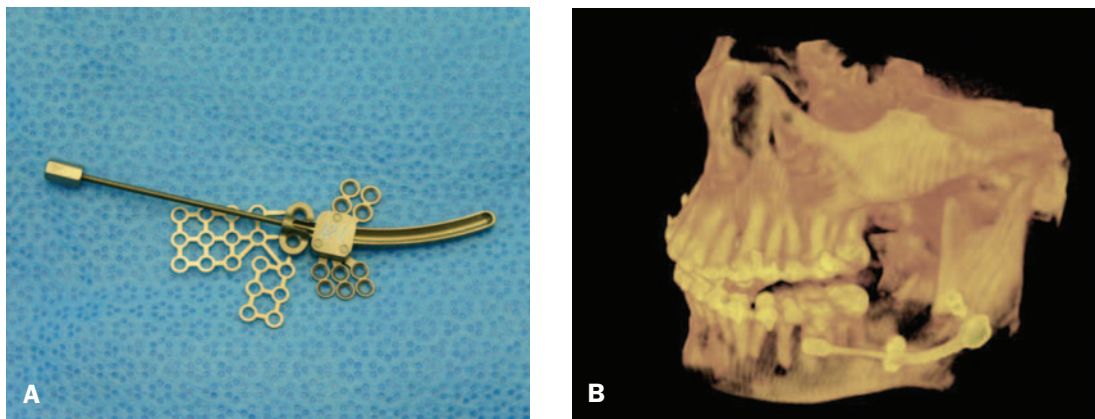


FIGURE 33-7 A, The distractor. B, The distractor in place and partially activated on a three-dimensional image of the mandible.

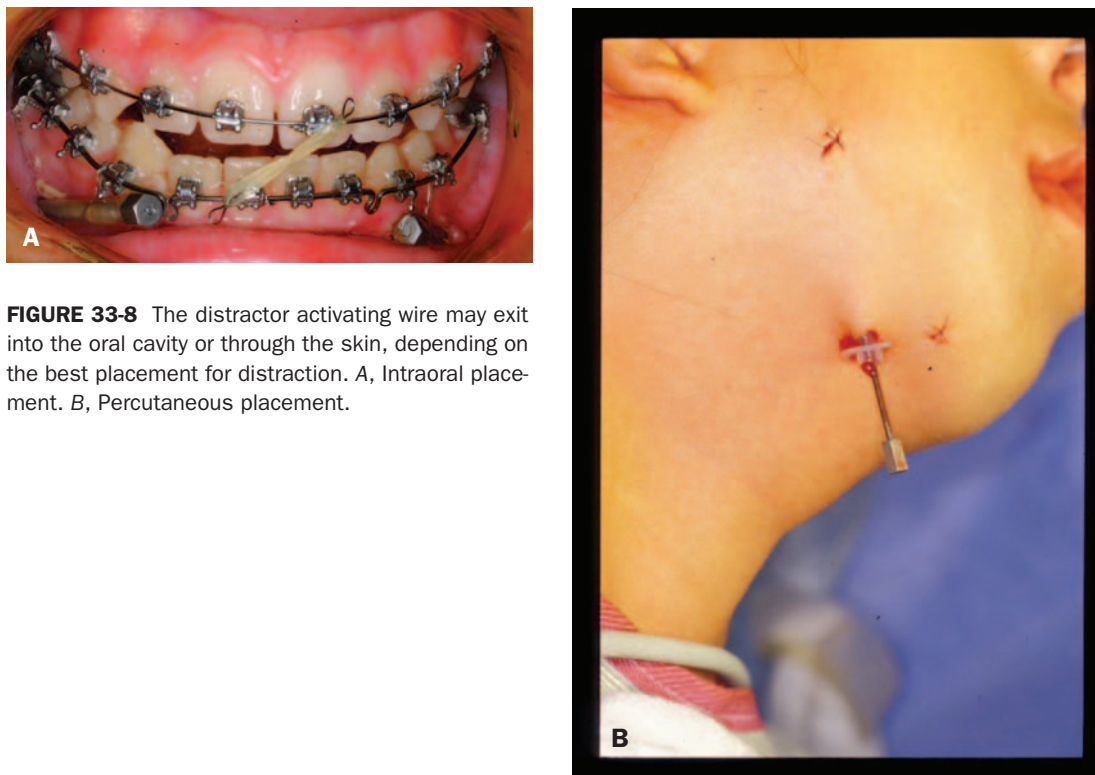


FIGURE 33-8 The distractor activating wire may exit into the oral cavity or through the skin, depending on the best placement for distraction. A, Intraoral placement. B, Percutaneous placement.

resorbable suture. The preferred technique in patients of over 5 years of age who have sufficient bone is a sagittal split osteotomy technique. After a 2- to 5-day latency period, depending on the circumstances and patient type, the screw is activated twice daily, 1 mm each time. Following completion of distraction, the threaded wire (screw) can be cut or removed, and the distractor becomes completely buried at this time until its removal.

One potential drawback of any distractor is the plane of distraction from a coronal point of view. Distraction should not be parallel to the mandibular body, but rather, parallel to the axis of distraction. This distraction can be achieved with shims placed under the distal fixation end (tooth-bearing portion of the mandible) of the device. In so doing, this will maintain the plane of distraction equidistant from each other, to prevent detrimental sequelae on the tempormandibular joints or loosening of the devices.

We believe the future of distraction to be phenomenal, and that within 5 years, its use will be commonplace in dealing with everyday craniofacial and dentoskeletal problems. It will be thought of as a different functional method of modifying growth and development. This device can be used in the younger patient once the diagnosis of mandibular deficiency has been made. It is possible to enucleate the third molar buds at the same time that the device is placed and the cortical bone cuts are made. Once the device is activated to the point where the treating dentist or physician feels the discrepancy has been successfully eliminated, it can then be removed after an appropriate waiting period for maturation of bony regenerate and as the patient matures. Any final dental occlusion adjustments can be taken care of at a later time in a more efficient and less expensive fashion, because the skeletal discrepancy has been resolved at an earlier age. This will decrease the adverse sequelae that happen when dental compensations are present owing to skeletal problems. This will give the patient a markedly better esthetic and functional result, and shorten the overall treatment time.

Case Reports

The sagittal split osteotomy presents several potential advantages over the straight-line osteotomy or corticotomy. The potential bone regenerative surface is larger; the initial distraction can be obtained while still maintaining bone interface contact; and the proximal fragment can be rotated into a more ideal position. The classic sagittal split ramus osteotomy described by Obwegeser is used.⁴¹ The inferior alveolar nerve can also be better protected by the splitting technique. The main limitation with this technique is the quality and quantity of the initial bone needed, which

must be sufficient for splitting. An intraoral curvilinear distractor also has advantages over other extraoral or intraoral linear distractors.

Generally, the intraoral distraction has a more one-to-one relation between the device and bone movement. Torque is minimized, thus loosening of the appliance and bending of the pins are not a problem.³ The device is also not seen, nor is it prone to external trauma or irritation, and thus patient inconvenience is minimized.⁴² The submerged curvilinear distractor was constructed to allow the distraction to follow the normal path of mandibular growth, which is a logarithmic spiral. Movement is thus simultaneous in both the vertical and horizontal planes.

Case 1

A 22-year-old woman with hemifacial microsomia (Pruzansky type IIb) presented with a shortened left side of the face. Radiographs confirmed this as being both left maxillary and mandibular hypoplasia. A Class I occlusion was evident, with a canted occlusal plane and large anterior open bite. Unilateral mandibular distraction was planned as the first stage of reconstruction. Presurgical orthodontic treatment was initiated to decrease dental compensations. The maxillary and mandibular first bicusps were extracted, and the mandibular left posterior segments were uprighted. An intraoral incision was made in the left mandibular sulcus in a similar manner for a sagittal split ramus osteotomy. The medial cut was performed in the usual manner, just above and ending posterior to the lingual. The lateral cut-through was performed according to the classic description, approximately 2 cm down the lateral side of the mandible, but still in the ramus. The split was then done in the usual fashion, without difficulty (Figure 33-9). A Logic 52 mm curvilinear distractor (OsteoMed Corp, Addison, TX) was then placed through the intraoral route (Figure 33-10). The actual curve had been chosen by presurgical prediction tracings and with the use of the logarithmic growth spirals. The mandibular segments were separated by advancing the distal segment 1 cm, and the proximal segment was also rotated counterclockwise by several degrees. The distractor was fixed by four 2 mm screws to the distal buccal cortical bone and the proximal segment lingual cortical bone.

The activating wire of the distractor was exited through the skin in the submandibular area by a stab incision. The oral incision was then closed in the usual fashion. No elastics or bimaxillary fixation were used. One week postoperatively, the distraction was started at 1 mm a day (Figure 33-11). When the distraction was complete, the external activating wire was removed under local anesthesia, and the device became completely buried. The total distraction was 43 mm, which

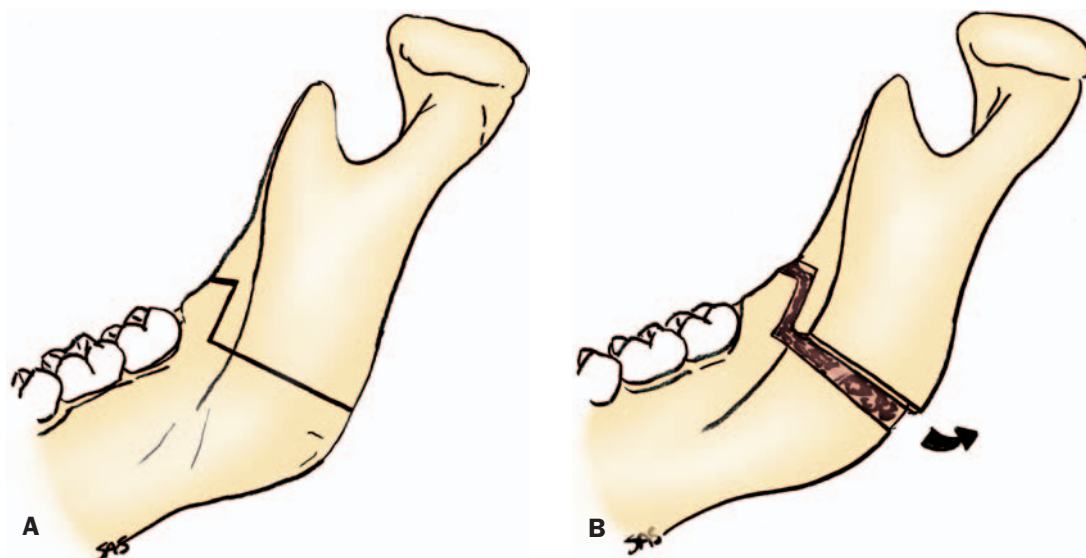


FIGURE 33-9 Sagittal split ramus osteotomy. A, Osteotomy lines, marked according to the classic technique. B, The sagittal split completed and the proximal segment rotated counterclockwise to realign the ramus prior to distraction.

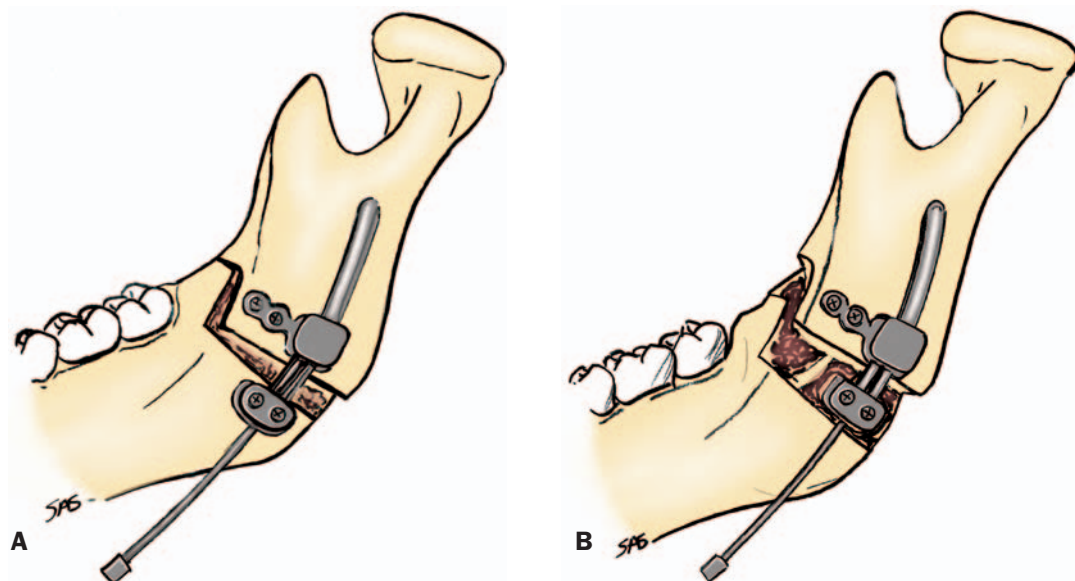


FIGURE 33-10 An internal distractor applied to the mandible after the sagittal split osteotomy. A, A distractor fixed to the proximal segment buccal cortical bone and the distal internal cortex through the split. B, Fixed in the usual fashion.



FIGURE 33-11 Preoperative radiographs of patient. A, Preoperative lateral cephalometric radiograph, demonstrating the short left mandibular ramus and canted occlusal plane. B, Preoperative panoramic radiograph. Note the small short left ramus and body of the mandible.

created a left lateral open bite of 32 mm (Figure 33-12). After distraction, the posterior bite was closed using very light orthodontic forces (2 oz 3/16 inch diameter elastics) and closure was accomplished by stabilizing one arch with labial and lingual arch wires while extruding the teeth of the opposite arch. After extrusion of the maxillary teeth had been achieved, the lingual arches and arch wires were flip-flopped and placed in the maxillary arch, and the same approach applied to the mandibular dentition to extrude these teeth individually and segmentally. The open bite closed in 9 months without difficulty. After extrusion, the teeth were rebracketed and releveled so that final root positioning could be achieved. To date, the posterior extrusion has held quite nicely 2.5 years post distraction.

Radiographic comparison showed that no posterior vertical height was lost during this interval. The open bite was closed by eruption of both the maxillary and mandibular dentition. Eruption of the mandibular dentition increased the mandibular body height on the left, which resulted in a more normal mandible (Figure 33-13).

Case 2

A 16-year-old woman presented with severe mandibular retrusion and a Class II malocclusion. In addition, she had a history of temporomandibular joint pain and dysfunction, which had been treated by conservative therapy. The treatment plan based on the above was to preoperatively level and align the dentition sufficiently to perform the mandibular advancement. In this case, distraction osteogenesis was chosen over routine orthognathic surgery because of the amount of advancement and the condylar resorption apparent on x-ray. Ultimately, the patient refused a genioplasty and rhinoplasty. The result has remained stable for over 3 years (Figures 33-14 through 33-19).

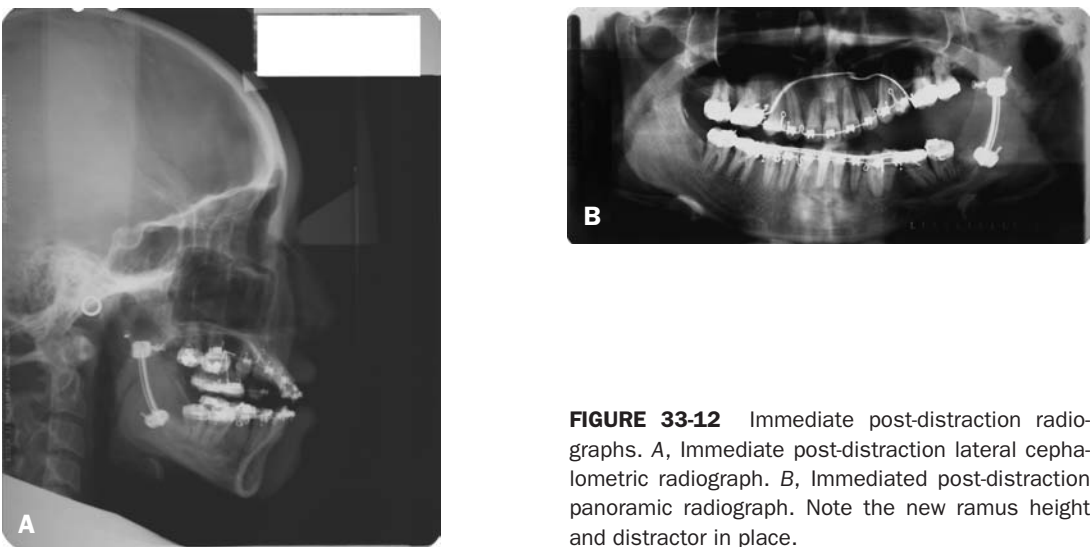


FIGURE 33-12 Immediate post-distraction radiographs. A, Immediate post-distraction lateral cephalometric radiograph. B, Immediate post-distraction panoramic radiograph. Note the new ramus height and distractor in place.

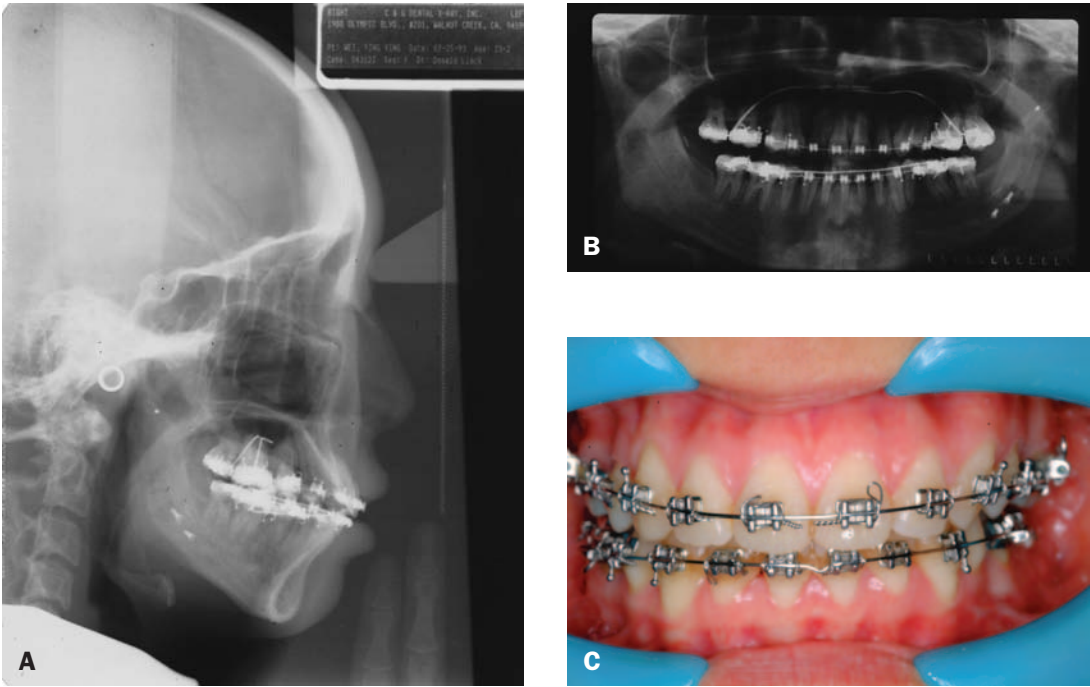


FIGURE 33-13 Long-term radiographs after removal of the distractor. A, Lateral cephalometric radiograph. B, Panoramic radiograph. C, Postoperative occlusion.



FIGURE 33-14 Preoperative frontal (A) and lateral (B) facial views.

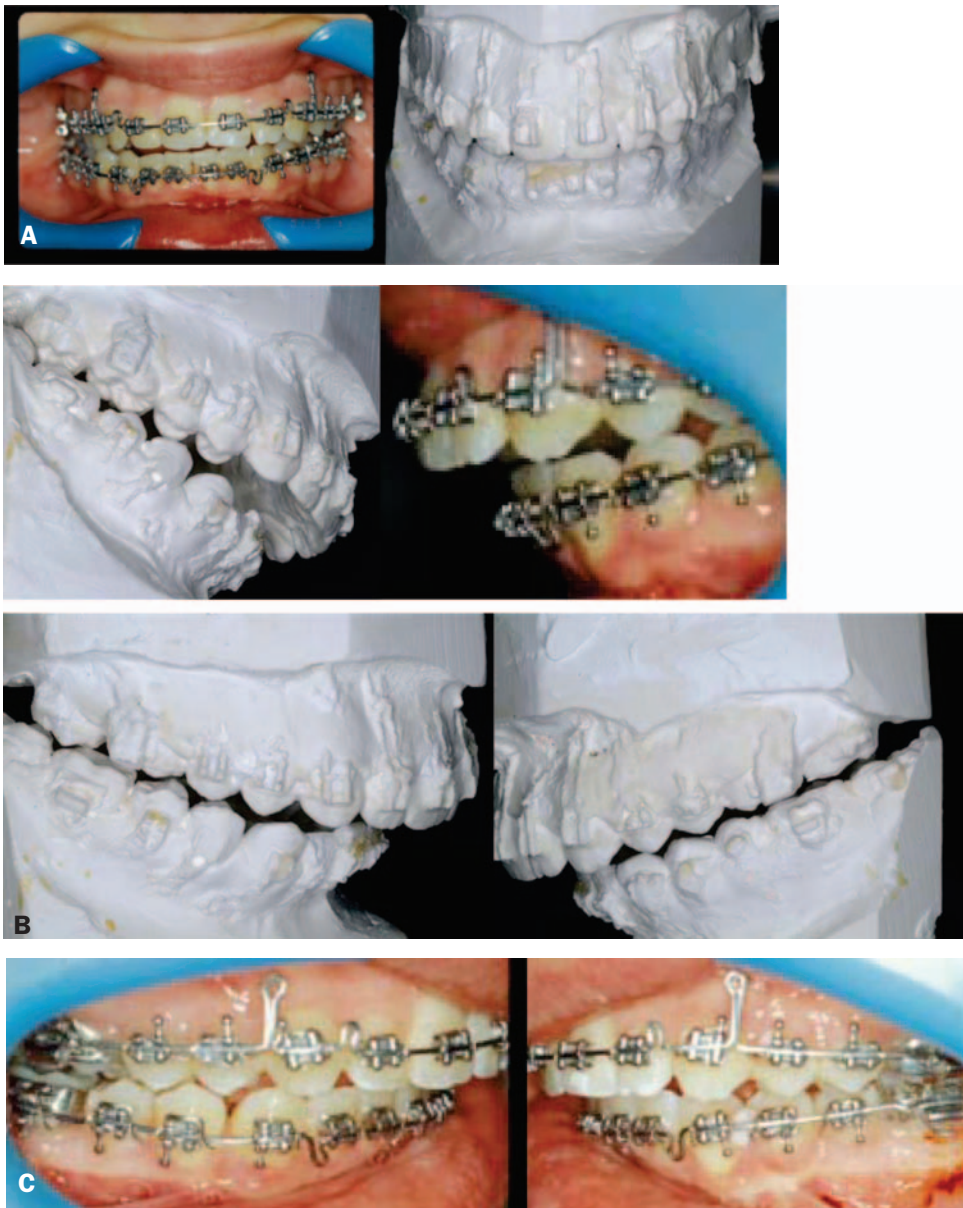


FIGURE 33-15 Frontal (A), right/left lateral (B), and intraoral occlusal (C) views preoperatively, also with preoperative study models.

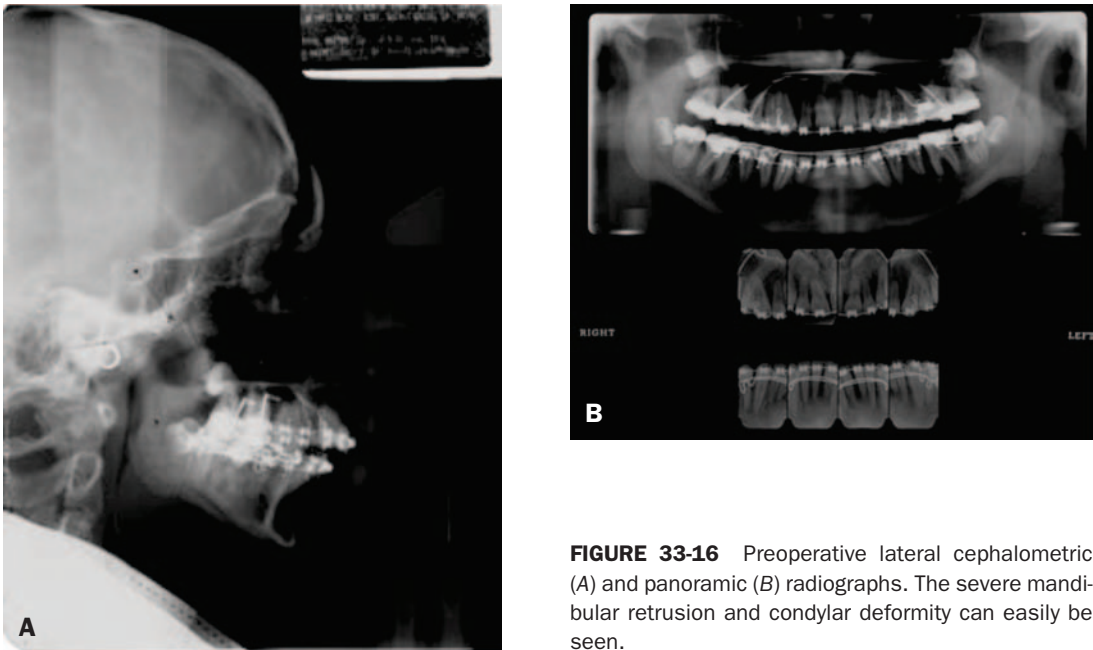


FIGURE 33-16 Preoperative lateral cephalometric (A) and panoramic (B) radiographs. The severe mandibular retrusion and condylar deformity can easily be seen.



FIGURE 33-17 Posttreatment frontal (A) and lateral (B) facial views.

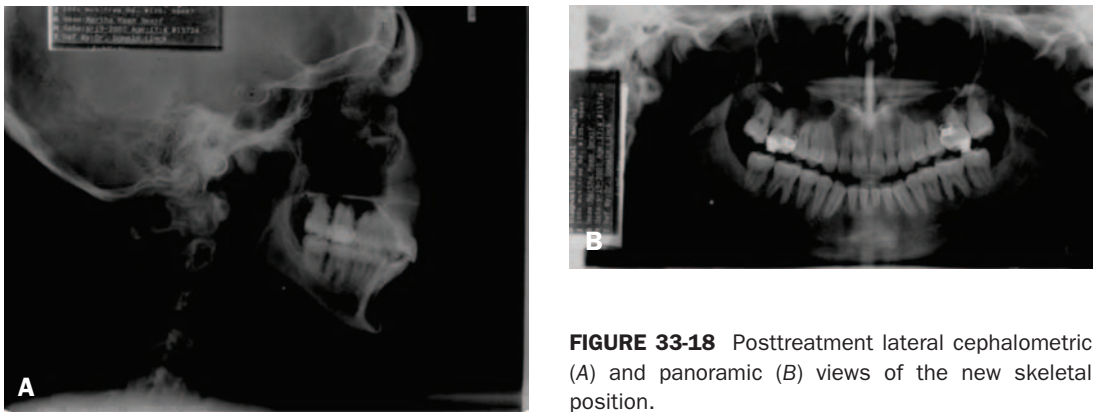


FIGURE 33-18 Posttreatment lateral cephalometric (A) and panoramic (B) views of the new skeletal position.



FIGURE 33-19 Postoperative occlusal views.

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Intraoral Distraction Osteogenesis: Our Devices and Treatment Concepts

Konrad Wangerin, Winfried Kretschmer and Werner Zoder

The principle of distraction of the upper and lower extremities was developed by Ilizarov in the former Soviet Union between 1950 and 1985.¹ In the late 1980s, miniaturized distractors were manufactured in Western Europe for use in hand surgery. Ilizarov and McCarthy exchanged ideas during a visit to New York, resulting in the first-ever distraction of malformed mandibles using transbuccally fixated hand surgery distractors. McCarthy and colleagues' publication in 1992 sparked off an extensive search for distraction indications and the frantic development of a variety of distractors for use in the craniofacial area of the skull.² As well as multidimensionally adjustable equipment for extraoral use, more comfortable, intraorally applied distractors were also developed, and these are used today in distraction of all parts of the craniofacial skeleton. Publications on intraoral mandibular distraction appeared first in 1994 by Wangerin and Gropp and in 1996 by Diner and colleagues.^{3,4} In 1995, Cohen and colleagues first treated a severe craniofacial microsomia by simultaneous distraction of the maxilla, the orbita, and the mandible using two distractors.⁵ Chin and Toth distracted the maxilla first, shortening the activation pin, which perforated the cheek as soon as possible after rapid maxilla advancement, thus avoiding scarring.⁶ Chin developed the equipment further to enable hidden Le Fort III distraction.⁷

Intraoral distraction methods do not restrict the quality of life; they avoid scar formation in the cheek areas, have the advantage of being invisible during use, are easy to use (Figure 34-1), and can be retained for unlimited periods. The sole existing disadvantage, the unidirectional distraction, was offset by Triaca and colleagues when they developed multiaxial mandibular distractors.⁸ Intraoral distraction in the craniofacial skeleton has now become a gold standard.

Mandibular Distraction in Congenital Malformation or Acquired Deficiency

Indications for distraction are all syndromes with mandibular malformation. A major symptom is

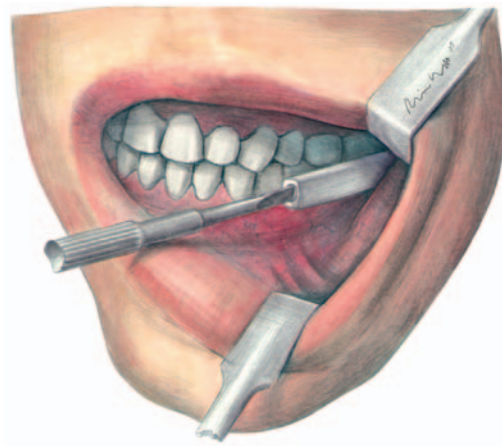


FIGURE 34-1 Demonstration of horizontal mandibular distractor, activated by turning the screwdriver anticlockwise.

airway obstruction in severe cases of mandibular retrognathia. Deglutition problems may also be caused by malformation of the mandible. Another indication is speech impairment owing to a reduced oral cavity size.⁹

The development of distraction first broke the unspoken law that osteotomies should not be carried out before bone growth is complete. Intraoral distraction is possible even in small children from the age of 3 to 4 years. A prerequisite is a sufficient thickness of cortical bone surrounding the mandibular body, necessary to fix the distractor miniscrews.

Acquired shortening of the mandibular body, ascending mandibular ramus, and condylar process can also be considered indications for distraction. These alterations may be caused by trauma or rheumatoid degeneration of the condyle; they may also be the result of bone infections or tumor resection. They occur mainly in adults, and distraction therapy is especially effective in the ascending ramus. In the past, the only solution was to reconstruct the ramus-temporomandibular joint unit by means of costochondral graft, a procedure that was not always successful, showing acceptable results in only one-third of

cases. Distraction is less complicated and more comfortable for the patient and has a very high success rate. A prerequisite for successful treatment is the postoperative integration of an interocclusal acrylic splint for 6 months to retain the resulting open bite until the ossification is complete.

Body Deficiency

Indication

A mandibular body that is simply too short is rare. It can occur unilaterally or bilaterally, in most cases in conjunction with a deficit of the ascending mandibular ramus. To reduce symptoms such as obstruction of the respiratory tract, difficult ingestion, or speech impairment, in some cases it is necessary to initially lengthen the mandibular body. This is often a prerequisite for a later, second distraction to elongate the likewise shortened ascending mandibular ramus.

Surgical Technique

Under general anesthesia or local analgesia, a posterior buccal vestibular mucoperiosteal incision is made, followed by subperiosteal exposure limited only to the buccal surface of the mandibular angle region while preserving the periosteal attachment to the lingual surface. A horizontal mandibular distractor 20 or 25 mm in length is inserted and fixed monocortically onto both sides of the planned osteotomy by means of one miniscrew per side, thus defining the direction of distraction. In most cases, distraction runs parallel to the occlusal plane (Figure 34-2, A and B) and less commonly obliquely, so that the distraction results in an open bite (Figure 34-2, C and D). In cases of severe unilateral hemifacial microsomia, it may at times be necessary to prebend the distractor miniplates to change the distraction direction (Figure 34-2, E-H) and to alleviate facial asymmetry. In such cases, all of the drill holes are bored in advance and the osteotomy is then marked with the Lindemann bur. The distractor is removed, and the osteotomy is performed. It is important to expose the inferior alveolar nerve

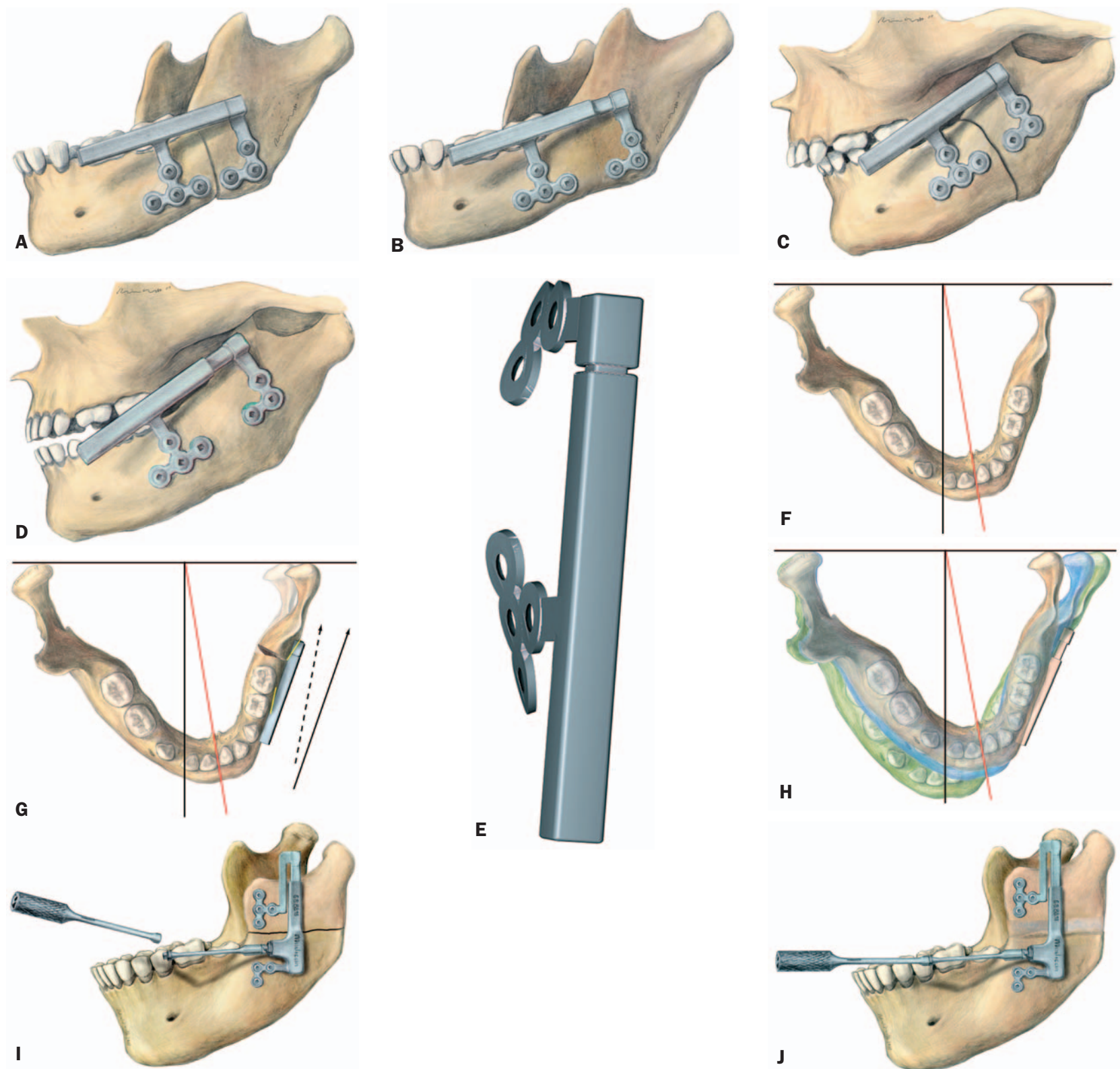


FIGURE 34-2 A, Horizontal mandibular distractor in a neutral position fixed to the mandible buccally parallel to the occlusal plane with monocortical 5 or 7 mm mini-screws. B, Situation after horizontal distraction of the mandibular body to compensate for a mandibular bony deficit. C, Horizontal mandibular distractor situated at an angle to the occlusal plane to lengthen the mandibular body and the ascending ramus. D, Oblique distraction: the result is an enlarged mandible with an open bite. E, Prebent miniplates on a horizontal mandibular distractor to laterally shift a rudimentary condylar process that extends into the oral cavity. F, Rudimentary shorter left ascending mandibular ramus with a noticeable midline shift to the left. G, After retromolar diagonal mandibular osteotomy. Fixation of the distractor with prebent miniplates and resulting lateral shift of the shortened left condylar process. The original distraction direction has changed (*unbroken arrow*). H, Distraction results in expansion of the mandible on the left side and positioning of the mandibular midline in the correct midline position. I, Congenital malformations of the mandible often show a deficit in the ascending mandibular ramus. The most common distraction is therefore extension of the ascending ramus. The vertical mandibular distractor is fixed to the buccal side. The distraction cylinder marks the direction of distraction. This must be carefully planned in each individual case. The distraction is rerouted by means of a gear mechanism so that the activation rod (which is jointed to make it flexible) comes easily to rest in the floor of the mouth. J, Distraction has lengthened the ascending ramus. If the osteotomy is situated in the area of cancellous bone, bone growth is unlimited. A lateral open bite results in the nonocclusal area, which will have to be supported by an interocclusal splint for 6 months.

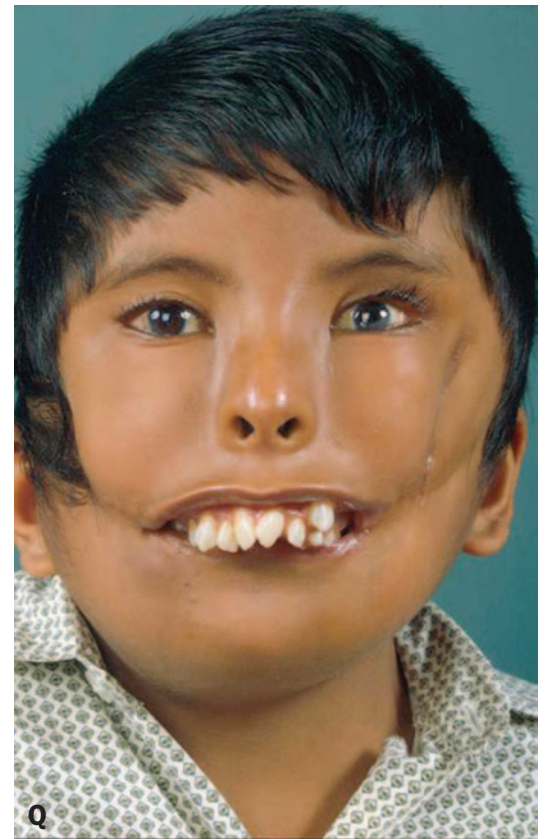
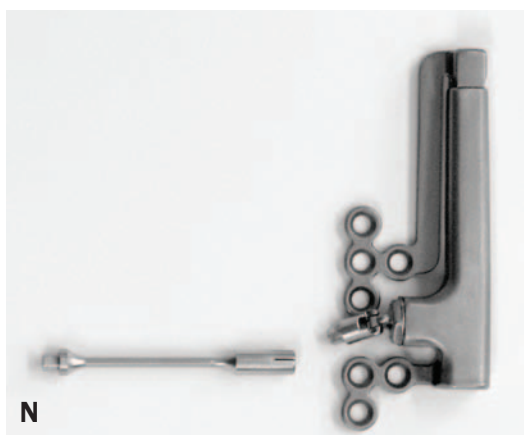


FIGURE 34-2. continued. *K*, In cases of vertical mandibular distraction, an easier determination of the vector of distraction is possible by intraoperative application of this pin, which can easily be fixed at an angle of 90° to the distraction direction. *L*, Intraoperative control of the parallelity of both vector determination pins. *M*, In cases of severe unilateral hemifacial microsomia, an operation simulation on a stereolithographic model is recommended. In this case, the distraction cylinder must be hidden under the zygoma and the miniplates significantly prebent. This planning possibility increases distraction accuracy. *N*, The new modification of the vertical device allows the mobilization of the activation pin after the end of distraction. The total submergence avoids infection of the distraction region. *O* and *P*, A 12-year-old patient with extreme mandibular retrognathia and a lateral facial cleft on both sides. *Q* and *R*, Improvement of the mandible position by means of first horizontal distraction on both sides.

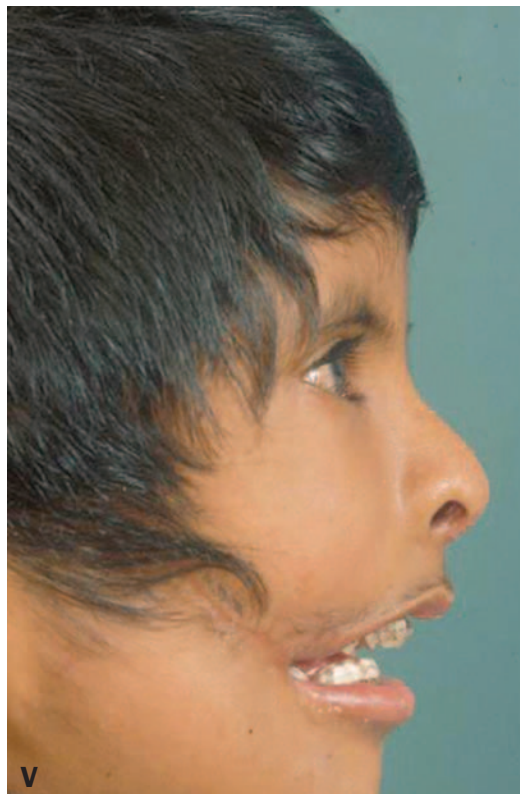


FIGURE 34-2. continued. S and T, Further improvement after second horizontal mandibular distraction at 13 years of age. U and V, Almost normal facial contours after orthodontic treatment and concluding bimaxillary correction at 14 years of age.

and completely split the mandible. This split should be checked, especially toward the medial periosteally covered mandibular surface. During the active bone growth period, there is always a risk of a greenstick fracture occurring. The distractor is then reinserted and fixed permanently onto both sides of the osteotomy with monocortical screws 5 or 7 mm in length. A test distraction should be performed so that any unforeseen problems can be dealt with. Ultimately, the incision is closed with resorbable sutures.

Ramus Deficiency

Indication

If the mandibular body is long enough, many cases with a deficiency of the ramus require vertical distraction. In our patients, this is the type of distraction we performed most often during the last decade (Figure 34-2, I and J).¹⁰

In these cases, planning the distraction vector is a prerequisite for successful treatment. Based on cephalometric analysis of the lateral radiograph, the vector can be defined and transferred during the operation. In individual cases, we checked the distractor position intraoperatively by vector determination pins (Figure 34-2, K and L) or by radiographic verification.¹¹ In other severe cases of hemifacial microsomia, operation planning was carried out with the aid of computed tomography (CT) and stereolithography, and the complete surgical procedure was simulated on a model skull (Figure 34-2M). During this procedure, the fixation plates of the distractor were preshaped, ensuring high accuracy when intraoperatively positioning the equipment.

The operative approach is identical to that in the horizontal mandibular area. Distraction is easily performed by patients themselves. With the aid of a mirror, the patient uses a screwdriver to turn the activation pin in the mandibular vestibule. It can be pulled out at the end of distraction for total submergence of the device and to avoid infection in the distraction area (Figure 34-2N).

Combinations

The close connection between horizontal and vertical distraction in the mandible has already been described. Depending on the primary presentation and the extent of the bony defect, procedures are planned individually for each patient. In the majority of cases, horizontal distraction is performed first to relieve primary symptoms, which can be done by the age of 3 or 4 years according to the severity of the respiratory obstruction. In the early teenage years, vertical distraction is performed to develop a bony mandibular angle. In a case of a severe bilateral facial cleft with extreme mandibular retrognathia,

we carried out two horizontal distractions 1 year apart, concluding therapy with a bimaxillary osteotomy at the end of skeletal maturity (Figure 34-2, O–V). Facial asymmetries caused by unilateral hemifacial microsomia in combination with mandibular retrognathia were treated with a combination of horizontal and oblique mandibular distraction and ultimately corrected by bimaxillary osteotomy.¹²

When indicated, these procedures can be undertaken in a consecutive manner 1 year apart.

Distraction in Orthognathic Surgery

Conventional osteotomies in orthognathic surgery do have anatomic and physiologic limits. Certain relapse tendencies after jaw repositioning cannot always be completely avoided. The risk of a relapse grows as the magnitude of acute surgical movement increases.

Distraction, however, can keep such relapses at a minimum because advancement of the jaw, or parts of the jaw, is performed gradually, in multiple daily increments, and as the distractor is worn intraorally, retention time is unlimited.

Distraction enables advancement over longer distances than conventional osteotomy. Chin and Toth provided convincing evidence of this.⁶ The advantages of distraction methods in comparison with conventional osteotomy can be seen in mandibular or maxillary advancement or in transverse expansion of narrow mandibles or maxillae.

Mandibular Retrognathia

Indication

An indication for parallel mandibular distraction is mandibular retrognathia with Angle Class II malocclusion. Parallel positioning of the distractors is necessary to avoid an increase in intercondylar distance (Figure 34-3, A and B). A prerequisite here is full skeletal growth and normal position of the maxilla. In comparison with routinely performed bilateral sagittal splitting of the mandible, it appears that gradual daily advancement of the mandibular body lacks harmful effects on the function of the mandibular joints, which are endangered by a possible malposition of the articular disk. Gradually stretching the suprahyoid musculature and the soft tissue surrounding the mandible reduces any sensation of tension, a problem that occurs especially in older patients. Retromolar diagonal osteotomy of the mandible during distraction does not damage the inferior alveolar nerve, providing another advantage over conventional sagittal splitting, a method that cannot completely eliminate nerve damage.

A final advantage of this method is the close cooperation with the orthodontist, who can

carry out the distraction and define the extent of distraction to fit in with his or her orthodontic treatment plan. Dental or skeletal relapses have not been noted in these cases up to now.

It should be mentioned that a deep bite provides the best occlusal results as distraction in these cases always has a tendency to form an open bite. In such cases, the use of the “floating bone principle”¹³ is possible to achieve a neutral occlusion: overcorrection into an edge-to-edge bite, removal of the distractor 1 week after distraction is finished, and insertion of loose elastics to slowly close the bite.

Surgical Technique

Planning Operation planning takes place with the aid of cephalometric analysis and definition of the distraction vector, which should run parallel to the occlusal plane. A plastic splint is manufactured on a plaster cast model of the mandible, with occlusal adjustment of the fitting surface and the upper side corresponding to the direction of distraction. An adjustment clamp is fixed onto the plastic splint with screws, into which the distractors are inserted parallel to each other. A complete simulation on a stereolithographic model is even more accurate (Figure 34-3, C–E).

Operation Under transnasal intubation anesthesia, a posterior buccal vestibular mucoperiosteal incision is made approaching the height of external oblique ridge on both sides of the mandible, followed by subperiosteal exposure of the buccal aspect of mandibular angles and the front of both ascending rami. Occlusal application of the plastic mandibular splint follows, and the adjustment clamp used to define the vector and the parallel position of the distractor is fixed onto the splint with screws. The ends of the clamp pass around the side of the lower dental arch and both oblique distractors are inserted and fixed parallel to one another. The miniplates of the distractors, which were prebent during the operation simulation, are now fitted, and the distractors are fixed with one screw each on both sides of the planned osteotomy line. All of the screwholes are drilled in advance, and the osteotomy line is marked. The splint is then removed, along with the adjustment clamp and the distractors. The horizontal retromolar osteotomy is now performed, and the inferior alveolar nerve is identified and secured. Both distractors are inserted, at this stage without the adjustment clamp, and screwed loosely into place. To ensure a parallel position of the distractors, the adjustment clamp is reinserted with the plastic splint. Both distractors are then fixed by tightening all of the screws. The adjustment clamp and splint are now removed, followed by test distraction on both sides and wound closure. The concluding distraction results in a Class I occlusion (Figure 34-3, F and G).

Maxillary Retrognathia

Indication

Up to now, the retrognathic maxilla was usually distracted extraorally. This was carried out with a halo frame, which was fixed with spikes onto the skull, which, owing to its size and visibility, naturally limited the length of the retention period. This resulted in relapses with a reduction in distraction distance of between 20 and 25%. The development and use of transantral distractors are new and allow an unlimited retention period and, consequently, a minimal relapse distance (Figure 34-3H).

Prerequisites for exclusive maxilla distraction to correct a malpositioned maxilla are orthodontic treatment with formation of congruent dental arches, completed skeletal growth, and normal position of the mandible.

In cases of extreme congenital maxillary retrognathia, an earlier maxillary distraction may be indicated, usually for psychological reasons. In this case, the maxillary space must at least be so far developed that the Le Fort I osteotomy can avoid damaging the high-lying canine tooth germs. A CT scan is indicated. Experience shows that distraction can begin at about 10 years of age.

Surgical Technique

Under transnasal intubation anesthesia, the maxilla is exposed through a standard Le Fort I incision at the height of the buccal vestibule from the region of the upper first molar to the contralateral first molar. After subperiosteal dissection of the complete maxilla and the lower nasal passages, the Le Fort I osteotomy is performed without mobilizing the pterygoid process. This is followed by a downfracture with complete mobilization of the maxilla (Figure 34-3I). Both transantral distractors are fixed in the area of the piriform aperture with each of the straight three-holed miniplates (Figure 34-3J). The distractor length is adjusted to fit the size of the maxillary space. This is done by using a screwdriver to insert the spike at the posterior end of the distractor into the front of the processus pterygoideus cranial to the osteotomy line (Figure 34-3K). Care should be taken to ensure that the distractors are in a parallel position (Figure 34-3L). The mobilized maxilla is now folded back, and the osteotomy border and the angled miniplates are screwed into the area of the canine fossa (Figure 34-3M). The extension pieces of the distraction axis are put into place and guided through the mucous membrane into the maxillary vestibule as the wound is sutured (Figure 34-3N). Daily distraction in the maxillary vestibule is problem free. Finally, the extension pieces are removed so that the end of the distractor disappears under the mucous membrane (Figure 34-3O). Open bites

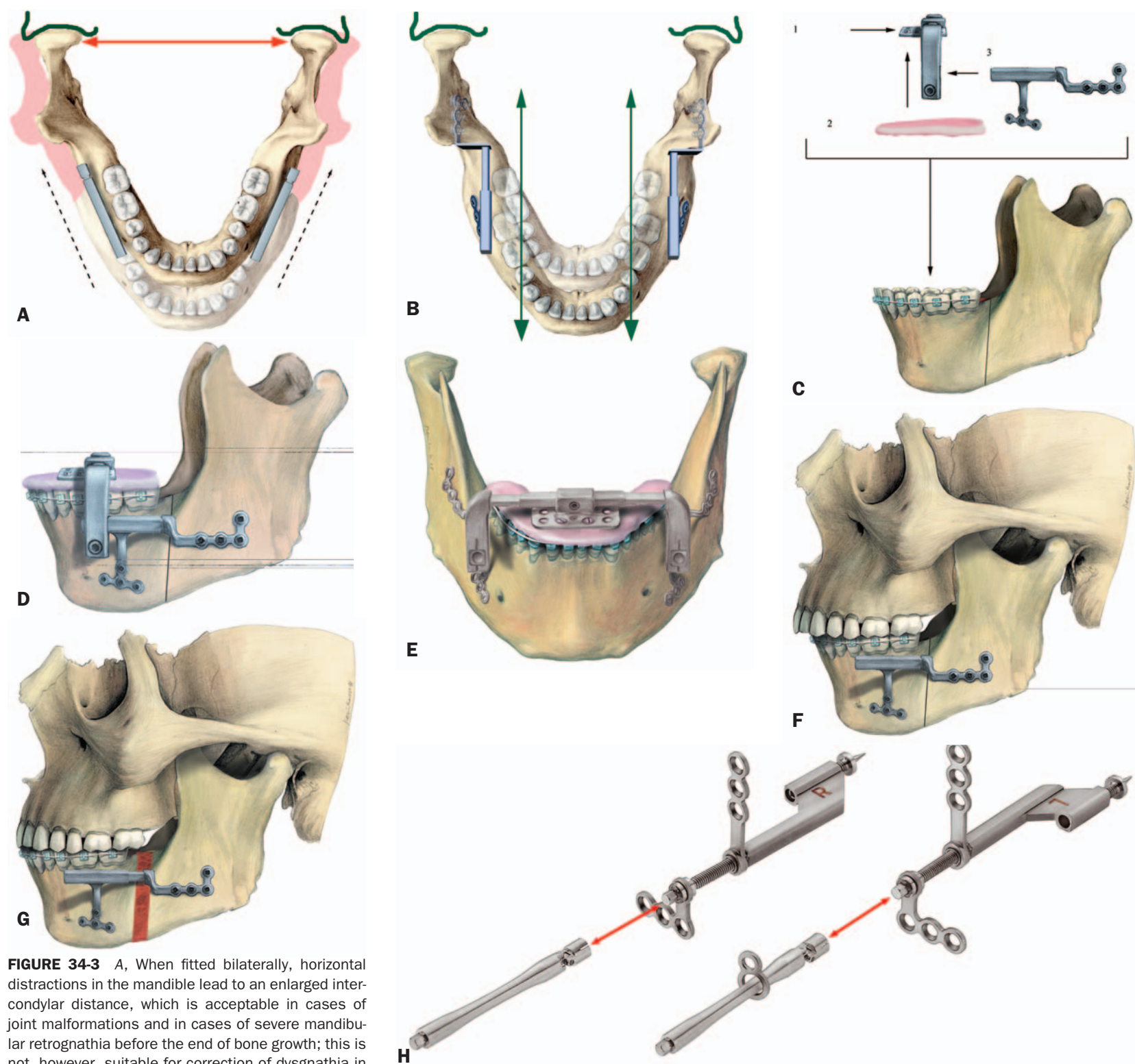


FIGURE 34-3 A, When fitted bilaterally, horizontal distractions in the mandible lead to an enlarged intercondylar distance, which is acceptable in cases of joint malformations and in cases of severe mandibular retrognathia before the end of bone growth; this is not, however, suitable for correction of dysgnathia in adults. B, Angled distractors, positioned on the buccal side of the mandible, allow parallel distraction of the mandibular body without greatly affecting the temporomandibular joints. C, Additional accessories are necessary for parallel mandibular distraction: (1) adjustment clamp with an onlay plate to define the direction of distraction and parallel fixation of both distractors; (2) one horizontal distractor on each side with angled posterior miniplates for fixation on the exterior of the ascending mandibular ramus; (3) occlusally adjusted plastic splint, the straight surface of which corresponds to the distraction direction. D and E, The onlay plate of the adjustment clamp is fixed onto the surface of the plastic splint, thus defining the direction of distraction. The plastic splint is fixed circularly onto the brackets with wires. The vertical parts of the adjustment clamp retain both distractors parallel to one another, and by pushing both vertical clamp elements together in the middle of the clamp, the distractor miniplates come to rest in the planned position on the buccal side of the mandible. They can then be fixed into place with screws. F, Start position through deliberate mandibular distraction to correct a Class II malocclusion and mandibular retrognathia. G, Parallel distraction of the mandible in Class I occlusion. H, Bilateral transantral distraction devices for maxillary advancement. Left and right, the device in the distracted position. The distraction screw tap is to be seen left and right. The size of the device can be changed with a screwdriver by extending the blunt spike, which will be stuck into the bony rear wall of the sinus. The straight three-hole miniplate, fixed onto the front border of the distraction cylinder, is fixating the device onto the piriform aperture. The angled miniplate is fixed on the canine fossa of the mobile maxilla to push it forward. Intraoperative distraction will be performed by anticlockwise rotation of the distraction screw (upper end of the red arrow). The angled extension piece (lower end of the red arrow) causes transmucosal activation in the maxillary floor of the mouth and may be removed after distraction is complete. For security reasons, a fixation ring around the extension piece (drawing only at the left device) can be stitched in the maxillary vestibule.

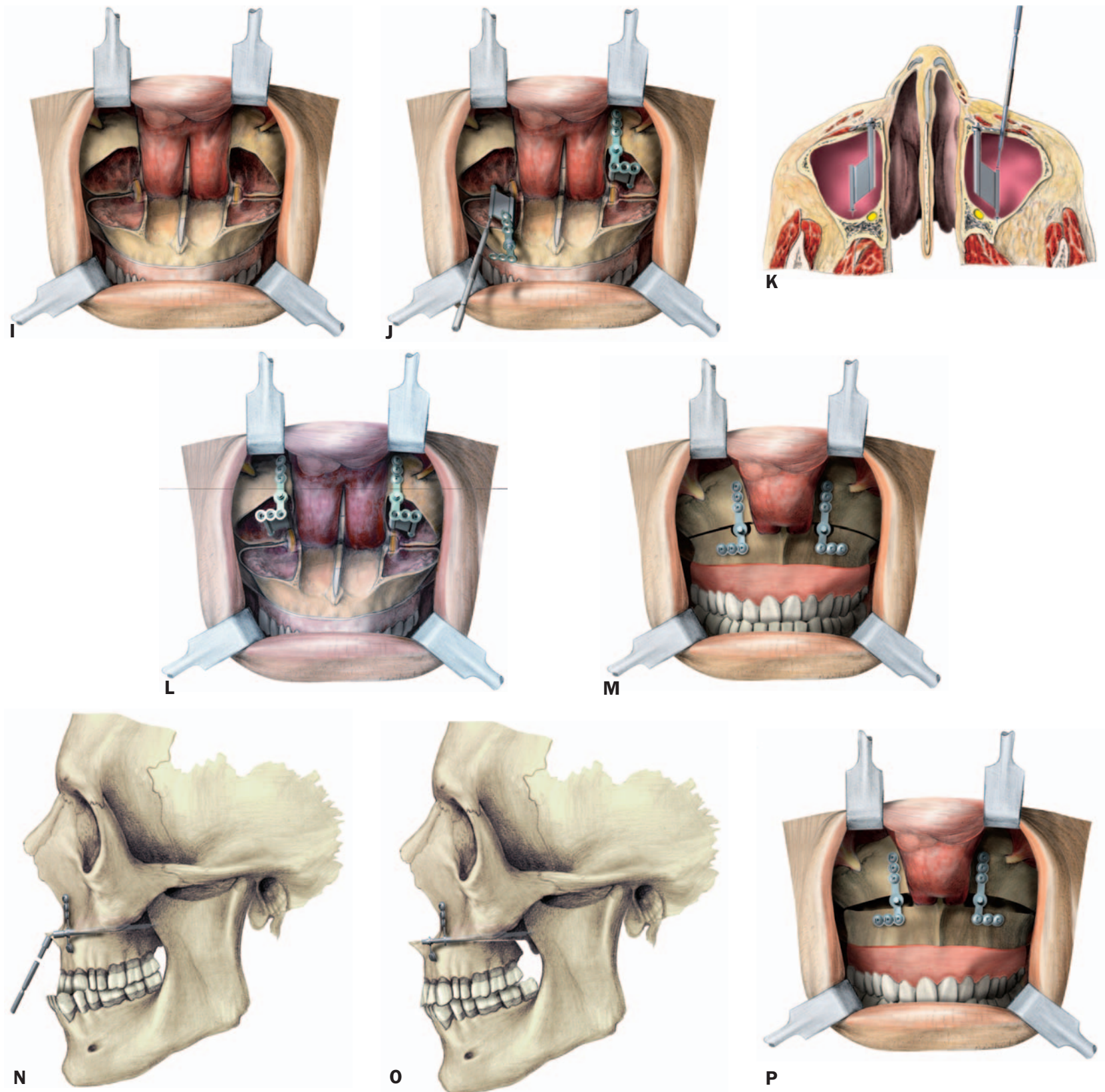


FIGURE 34-3. continued. *I*, Le Fort I osteotomy with downfracture: the greater palatine neurovascular bundle is dissected. Damage to the posterior wall of the maxillary sinus must be avoided as it serves as a distal support for the distractors. *J–L*, Fitting the transantral distractor, whose rear spike is extended with the screwdriver in accordance with the depth of the maxilla and inserted into the bony rear wall of the maxillary sinus lateral to the neurovascular bundle. The parallel position is achieved by fixation of the distractor to the piriform aperture. *M*, The mobile maxilla is now folded up and with the aid of the angled miniplates is fixed on the lateral upper border of the osteotomy near the canine fossa. *N*, The extension segment is placed onto the distraction rod, and a joint is used to guide it through the mucous membrane into the maxillary vestibule, enabling a problem-free distraction to protrude the retrognathic maxilla. *O*, After distraction is completed, the extension segment is pulled out through the mucous membrane, with the distractor thus remaining completely covered by tissue. The duration of the subsequent retention period is unlimited. *P*, The direction of distraction can be varied, but it is essential to plan it well before surgery. Vertical rearrangement of miniplate fixation can also be used to close an open bite.

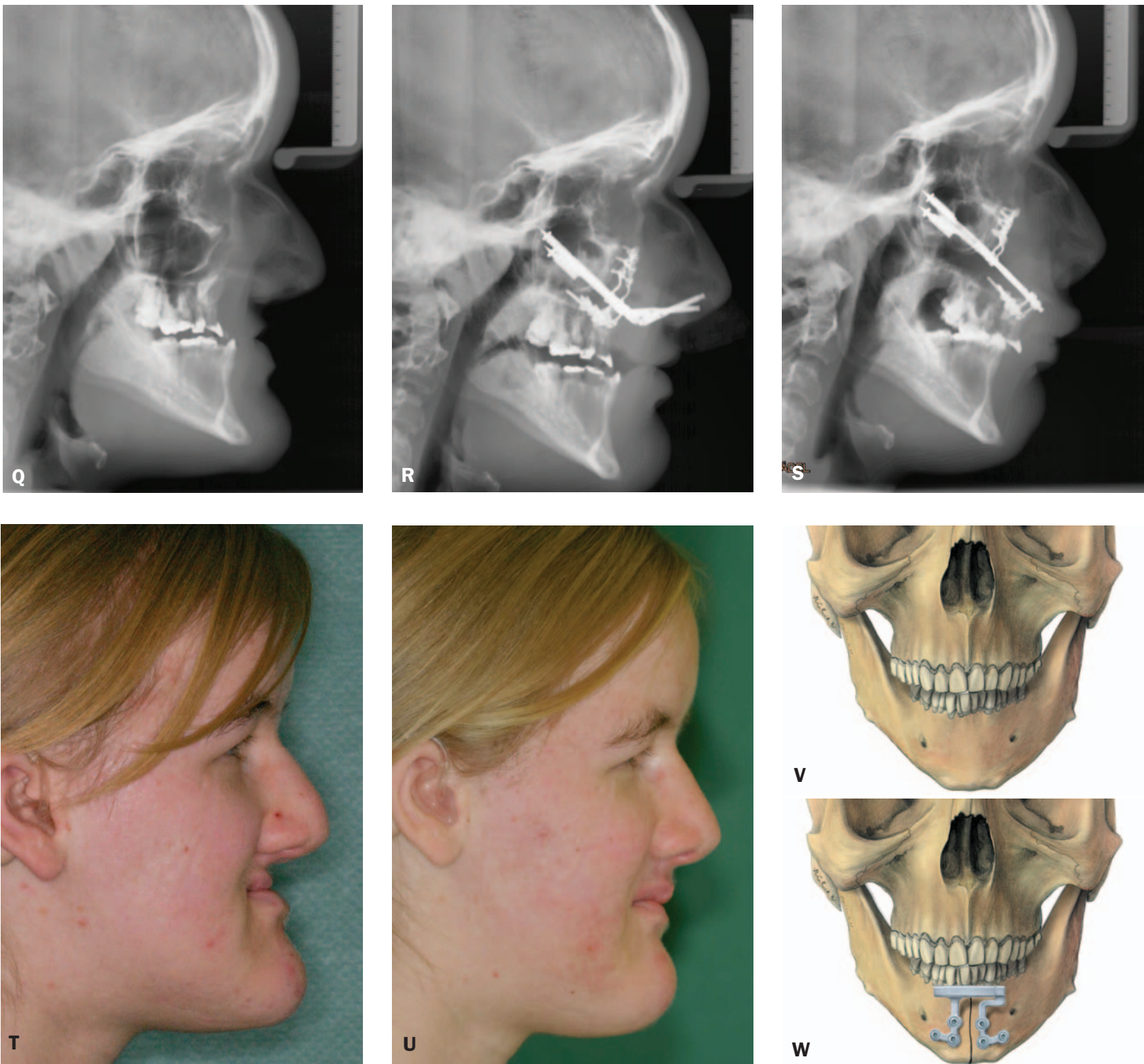


FIGURE 34-3. continued. Q–S, Lateral cephalograms of a 12-year-old girl with a congenital midface deficiency and hypodontia, preoperatively and during transantral maxillary distraction and at the end of distraction. T and U, Lateral facial appearance before and after maxillary transantral distraction. V, Indication for transverse mandibular distraction: a narrow mandible with frontal crowding. W, A mucosal incision is made in the mandibular vestibule under local analgesia, the mentalis muscle is dissected, and the distractor is temporarily screwed in. After complete median osteotomy, the distractor is then replaced with closure of the mucous membrane.

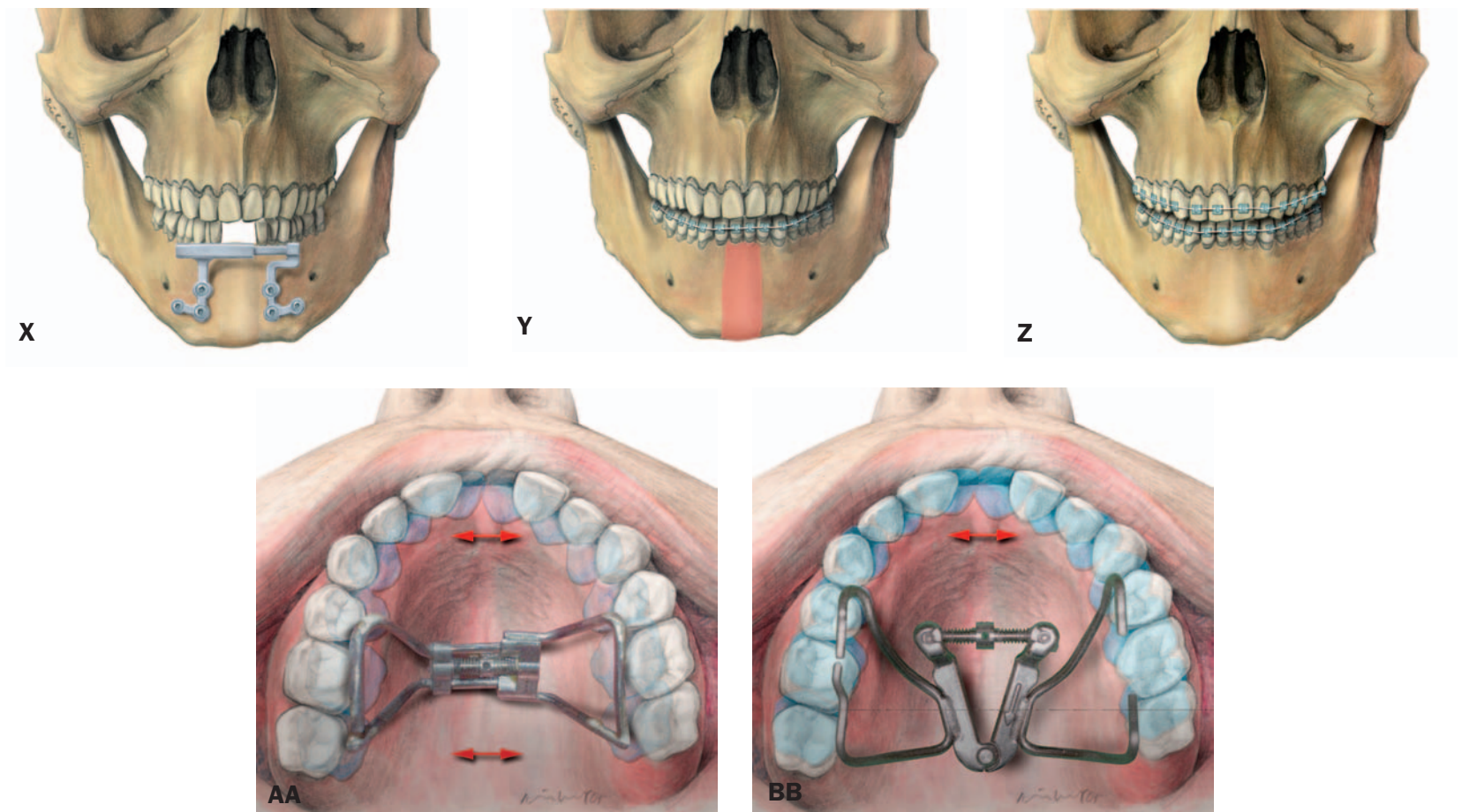


FIGURE 34-3. continued. X, To ensure that the incisors in the vicinity of the osteotomy do not loosen or wander into the distraction gap too soon, they are fixated orthodontically so that a wide diastema ensues. Y, After about 2 months, the teeth are orthodontically moved into the new bone-filled gap until the dental arch is accurately aligned. Z, The upper dental arch must be aligned accurately to obtain a Class I occlusion by the end of the treatment. AA, Transverse maxillary distraction with a transversally tooth-fixed extension screw to evenly expand the whole dental arch transversally in the front and in the canine area. BB, Fan-like maxillary distraction for anterior widening, producing a wide diastema. Even the opposite transversal distraction is possible by turning the device around 180° to widen the posterior parts of the maxilla.

can also be closed if the distraction direction in the area of the piriform aperture is lowered (Figure 34-3P).¹⁴ Such an anterior vertical distraction direction was successfully performed in an 12-year-old girl with hypodontia and severe midface deficiency. The radiologic and clinical follow-up is shown in Figure 34-3, Q to U.

Transverse Mandibular Deficiency

Indication

Transversal dental arch discrepancies caused by too small mandibular dental arches (Figure 34-3V) can be treated successfully with transversal median mandibular distraction. Indications might include facial types with a narrow mandible, crowding of the lower frontal dental segment, when a bilateral premolar extraction with a gain of 14 mm space is considered too large, and a front tooth extraction with a gain of 5 mm space too small. The gain of space between 5 and 14 mm is an absolute indication for transverse mandibular distraction. A prerequisite is an exact treatment plan and orthodontic space analysis,

taking into consideration the anterior-posterior position of the frontal teeth.

Follow-up examinations of our patients to date have shown that transversal mandibular distraction not only promotes bone growth with formation of a strong mandible; it also serves to increase the distance between the canine teeth, enabling the use of alternative orthodontic treatment methods. To date, orthodontic therapy was built up around a constant distance between the lower canine teeth, which could not be influenced by therapy.

Surgical Technique

Following local analgesia, an anterior labial vestibular mandibular incision is made beyond the reflection of the mucogingival junction well into the mobile mucosa. The mentalis muscle is dissected bilaterally, the median osteotomy lines are marked, and both angulated distractor miniplates are prebent. They are then temporarily fixed on both sides with a miniscrew 7 mm in length. The distraction cylinder should be lying horizontal at

the level of the height of the gingival margin of the incisors. Then all of the remaining holes are drilled, and the distractor is once again removed. The mandibular symphysis is sectioned with a saw and levered apart with a chisel so that it is completely fractured and no interradicular manipulation is necessary. In case of crowding, this could lead to tooth root damage. The distractor is reinserted and completely fixated with monocortical screws (Figure 34-3W). A test distraction is carried out, and the wound is closed. After healing, distraction can be carried out according to plan (Figure 34-3X). The tooth movement into the diastema should be carried out in close cooperation with the orthodontist, who can, at the same time, begin to form the upper dental arch (Figure 34-3, Y and Z).

Transverse Maxillary Deficiency

Indication

A narrow maxilla can be corrected orthodontically and surgically. Rapid maxillary expansion is a therapeutic measure that is carried out during

the skeletal growth period by the orthodontist alone. The median maxillary suture can be broken by activating a transversal extension apparatus that is fixed to the teeth, enabling transversal widening of the maxilla as required. After skeletal growth is complete; however, this method is relatively unreliable and needs operative assistance. It is possible to perform a purely transversal parallel expansion of the maxilla, resulting in a diastema and expansion of the lateral dental arch segments.

A therapeutic variation is the use of the fan-like expansion screw, which becomes necessary when the maxillary tooth bow is underdeveloped in the front and needs to be expanded obliquely. At the rear of the maxilla, expansion is hardly ever achieved (Figure 34-3, AA–BB). Also bone-borne devices are used in cases of periodontitis or partial edentulism; however, the directional control over the movement of the maxillary segments is largely unpredictable, owing to poor fixation of the deliberately small-sized fixation part of the device.

Surgical Technique

After the premolars and molars have been separated and the distractor has been worn temporarily, under transnasal intubation anesthesia, an incision is made in the midline of hard palate and in the maxillary buccal vestibule from the region of the second premolar to the contralateral second premolar. After exposure of the median hard palate and the maxilla including the lower nasal passages, a bilateral Le Fort I osteotomy is performed, followed by a paramedian bilateral sagittal palatal osteotomy via the approach on the hard palate. The two osteotomy lines meet in the midline in the area of the premaxilla so that both maxillary segments can be mobilized between the two central incisors after osteotomy of the anterior nasal spine and anterior median osteotomy. Also, in the Le Fort I plane, both maxillary segments are mobilized without performing a downfracture. To avoid tipping during transversal distraction, wedge-shaped bone pieces are removed at the region of the zygomatic buttresses on both sides. The final step is wound closure and cementing of the distractor onto the teeth.

Combinations

Of course, it is possible to perform distraction of the maxilla and mandible at the same time. This indication is seen in occasional cases of a narrow jaw with frontal crowding. Combined orthodontic rapid palatal expansion with transverse mandibular distraction may certainly, in some cases, be justified during puberty.

Conclusion

In its early days, distraction therapy gave rise to a certain euphoria as the indications and



FIGURE 34-4 A, Treacher-Collins syndrome before multistep treatment. B, Complete alteration of facial mimic with elimination of the typical syndrome stigmata after the following surgical steps: bilateral zygoma augmentation, vertical mandible distraction on both sides, bimaxillary correction, shift of the skin-muscle flap in the lateral corner of the eye, formation of lid creases in both upper lids, three chin corrections with bone transplants, and lipofilling of the zygoma and mandibular region with abdominal fat.

equipment development appeared to be inexhaustible. Many wrong paths were taken. Thankfully, complications caused by inefficient distractors and faulty operation techniques are now a thing of the past.

Intraoral distraction techniques have replaced extraoral methods. Although Ilizarov recommended beginning distraction 1 week postoperatively,¹ we have learned that it is advisable to begin distraction as early as the third postoperative day in children and the fourth postoperative day in adults. The distraction speed of 1 mm, as described in the literature, is also variable. In children, we distract 0.80 to 1.0 mm mornings and evenings (1.6–2.0 mm per day) to prevent premature ossification, and in older patients, we suggest only 0.4 to 0.5 mm mornings and evenings (0.8–1.0 mm per day) to avoid infections and osteomyelitis.

It is now possible to improve severe facial deformities with simple procedures to normalize the functions. A therapy method formerly reserved for adults has been extended to use in children. We now know that distracted bone also continues growing, although it later always lags behind the growth of normally formed bony structures.

It is possible to repeat distraction without hesitation after a year. In severe syndromes, distraction may be combined with all other operative treatment methods (Figure 34-4, A and B).^{12,15}

Experience over the last 12 years has shown that distraction has become an indispensable part of therapy of congenital malformations and acquired bony defects in the craniomaxillofacial area.

The concept of intraoral distraction describes standardized and systematic ways to safely and satisfactorily treat malformations during and after the skeletal skull growth period. In severe cases, this enables a therapy plan covering several time periods, resulting in ultimate success.

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Surgical Treatment of Inferior Alveolar Nerve Injuries Associated with Orthognathic Surgery in the Mandibular Ramus

Roger A. Meyer

Orthognathic surgical procedures on the mandibular ramus, including intraoral vertical ramus osteotomy (IVO), sagittal split ramus osteotomy (SSRO), and osteotomy for distraction osteogenesis (DO), subject the inferior alveolar branch of the mandibular division of the trigeminal nerve to varying degrees of risk of injury either at the time of the operation (IVO, SSRO, DO) or during the subsequent mandibular lengthening process (DO).

This chapter provides suggestions for reducing the risk of inferior alveolar nerve (IAN) injury associated with mandibular ramus surgery. Management of IAN injuries is presented based on the principles of microneurosurgical treatment I used for a large series of peripheral trigeminal nerve injuries (666 operations) from various causes.¹

Risk Factors

A number of factors are associated with increased risk of permanent sensory nerve dysfunction following mandibular orthognathic surgery.² Patients should be made aware of this information as part of the preoperative informed consent discussion.

Patients older than 40 years of age have diminished healing capacity compared with children, adolescents, and young adults. As we age, impaired nerve tissues may have less potential for complete healing. The older the patient, the less he or she is capable of adapting to sensory changes in the face or mouth. Intractable pain is more likely to develop from a nerve injury in an older patient, whether or not surgical repair is attempted.

Diabetes mellitus, heart or peripheral vascular disease, and other conditions that cause a compromised immune system interfere with

normal healing of nerve injuries. Peripheral neuropathy associated with diabetes may predispose the nerve injury patient to dysesthesias, which are difficult to control. The nature of the nerve injury influences whether the nerve has a chance to heal spontaneously or requires surgical intervention. Injuries in which the structural integrity of the nerve is partly (Sunderland III) or completely (Sunderland I, II) maintained are less likely to undergo retrograde reaction in the cell body and distal axonal death and degeneration than are injuries in which the nerve is partially (Sunderland IV) or completely (Sunderland V) crushed, stretched, chemically or thermally burned, or otherwise rendered incapable of transmitting an impulse (Sunderland VI).

Surgery in more than one location in the mandible, such as a horizontal sliding anterior osteotomy (genioplasty) in conjunction with bilateral ramus osteotomies (IVO, SSRO, DO), creates additional risk for the IAN. Lastly, because of the technical requirements of mandibular orthognathic surgery, the experience of the surgeon and the frequency with which he or she performs the procedure are directly related to the risk of nerve injury.

Prevention

Modifications of surgical techniques during mandibular ramus orthognathic operations may reduce the risk of IAN injury. Even applying the best surgical skill, however, cannot totally eliminate the risk of nerve injury.

Injection of local anesthetic into the pterygomandibular space to block the IAN should be accompanied by aspiration to prevent intravascular injection and injury to the adjacent nerves (IAN and lingual nerve). With the patient

under general anesthesia, no paresthesia will be elicited. However, if there is a bloody return on aspiration, the needle should be withdrawn 2 to 3 mm and aspiration repeated. Once there is a negative (bloodless) aspiration, the injection is completed with less likelihood of direct trauma to the IAN or lingual nerve.³

Direct trauma to the IAN is best avoided by using the SSRO for DO, as suggested by Whitesides and Meyer,⁴ rather than the through-and-through osteotomy around the IAN, as originally described by McCarthy and colleagues.⁵ During initial cuts through cortical bone with a drill or saw, the IAN is protected in the pterygomandibular space by a channel or medial ramus retractor (Figure 35-1). After the horizontal cut through

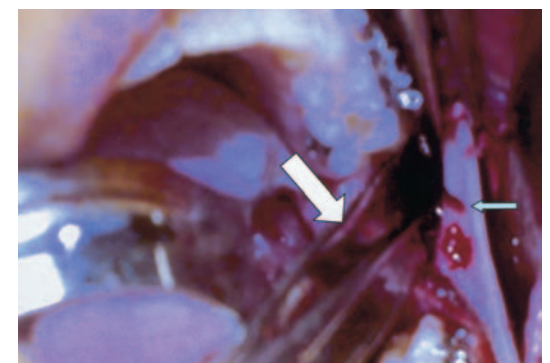


FIGURE 35-1 The inferior alveolar nerve in the pterygomandibular space is protected by a channel or medial ramus retractor (*large white arrow*) during the horizontal osteotomy (*small white arrow*) on the medial surface of the mandibular ramus by a saw or drill.

cortical bone is completed on the medial surface of the mandibular ramus and extended along the external oblique line and the vertical cut has been made through the lateral cortical bone from the external oblique line to the inferior border of the mandible, curved osteotomes are used to begin the separation of the proximal (ramus and condyle) and distal (tooth and IAN bearing) segments of the mandible. Spreaders are used to continue slowly separating the mandible into proximal and distal segments until the IAN is visualized (Figure 35-2). If necessary, the IAN is carefully removed from the proximal segment using small nerve hooks (Figure 35-3). Bone removal to unroof the inferior alveolar canal (when it contains the IAN in the proximal segment) is done with very small osteotomes. Loupes of 2.5 to 3.5 magnification are helpful for good visualization. Once the IAN is properly positioned in the mandibular distal segment, the osteotomy is rapidly completed with

larger osteotomes and/or the spreaders. The medial surface of the proximal mandibular segment is relieved of sharp or irregular bone with a large round or pineapple-shaped bur in a high-speed handpiece (Figure 35-4). Smoothing the inner surface of the proximal segment reduces the risk of injuring the IAN by sharp bone or compressing the nerve between the proximal and distal segments.⁶ When attaching the distraction device to the mandible, take care to avoid placing monocortical fixation screws directly over the underlying IAN. The screws may penetrate more deeply than estimated and may contact or penetrate the IAN. Once DO is initiated, limit elongation to no more than 1 mm/d (0.5 mm twice daily).^{7,8}

Throughout the operation, careful surgical technique that avoids direct mechanical injury to the IAN is the desired *modus operandi*.

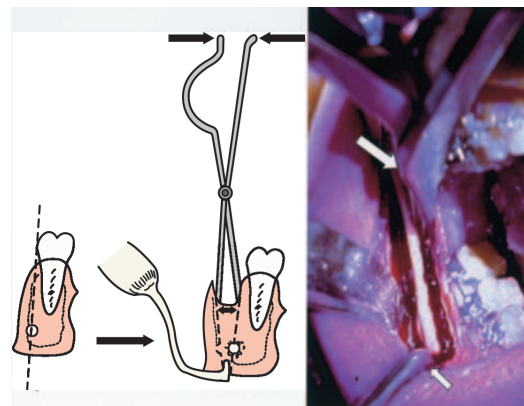
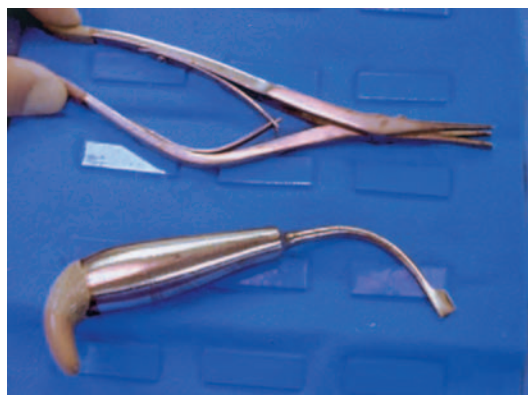


FIGURE 35-2 Spreaders gradually separate the proximal and distal mandibular segments during a “sagittal split” osteotomy. A, The superior border spreader (*above*) and the inferior border spreader (*below*); B, the right mandibular ramus is separated by superior (*large white arrow*) and inferior border (*small white arrow*) spreaders until the inferior alveolar nerve is visualized.

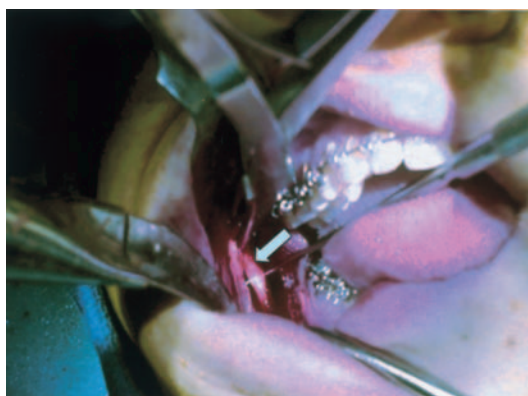


FIGURE 35-3 The inferior alveolar nerve (IAN) (*arrow*) is carefully lifted out of the right inferior alveolar canal groove in the proximal mandibular segment by a nerve hook. Separation of the mandibular proximal and distal segments is maintained with spreaders. In some instances, bone removal with fine osteotomes is needed to mobilize and reposition the IAN.

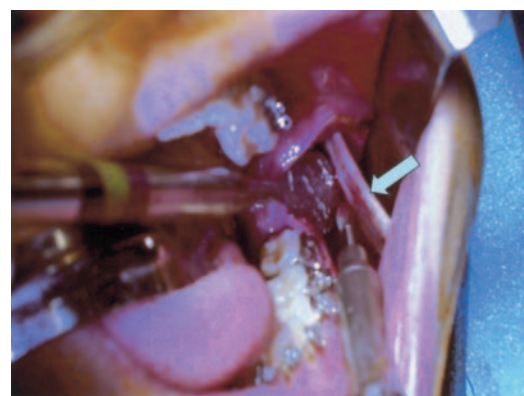


FIGURE 35-4 Sharp or irregular bone is removed from the medial surface of the left proximal mandibular segment (*arrow*) with a large bur. The left inferior alveolar nerve is protected by a large (Henahan) retractor.

Indications for and Timing of Nerve Repair

Peripheral nerve injuries are described as open or closed. Open nerve injuries are directly observed by the surgeon at the time they occur during a surgical procedure. Closed injuries are not seen during the surgical procedure but become apparent in the postoperative period when the patient complains of sensory aberration (numbness, hypersensitivity, pain) in the distribution of the IAN.

An open injury (partial or complete severance) of the IAN that occurs during a mandibular ramus osteotomy can be repaired at that time if deemed appropriate and if the surgeon possesses microsurgical skills and the necessary magnification, instruments, sutures, and trained assistants are available. The question then arises regarding whether to initiate DO 7 days following osteotomy, as is the usual practice. At that time, the connective tissue layers (epi-, peri-, and endoneurium) within the repaired nerve will have begun to heal. However, whether they will withstand the forces of elongation applied to the mandible has not been determined by controlled studies. Further, the severed axon-containing fascicles within the nerve will be pulled apart as distraction proceeds over the next 2 to 3 weeks. The final gap between proximal and distal nerve stumps may easily exceed 1 cm. The potential for regeneration of axons across such a gap is certainly compromised without taking additional measures (see Principles of Microneurosurgery, below). If, in the judgment of the surgeon, immediate repair of the injured IAN is not to be done, the proximal and distal limbs of the nerve are gently replaced into the inferior alveolar canal and approximated without suturing. The patient is then followed expectantly as described below for closed nerve injuries.

Sensory dysfunction of the IAN is expected after mandibular ramus osteotomies. Numbness of the lower lip and chin is a nearly universal early postoperative complaint. After SSRO and DO, but uncommonly after IVO, persistent sensory symptoms should be evaluated by neurosensory testing (NST) beginning at 4 weeks following surgery. Standard tests for response to pain or temperature, static light touch, and spatiotemporal factors (stimulus localization, moving brush stroke identification, two-point discrimination) have been evaluated by Zuniga and colleagues and were found to be accurate and reproducible.⁹ A discussion of neurosensory evaluation is beyond the scope of this chapter, and the reader is referred to Zuniga and colleagues⁹ and others^{10,11} for further study.

It is recommended that closed IAN injuries be followed by periodic review of the patient's history to track the progress or resolution of symptoms and by serial NST at 4-week intervals.

Patients who remain anesthetic (no responses to NST) at 12 weeks after surgery undoubtedly have a neurotmesis¹² or a partial severance, complete severance, or mixed combination injury (Sunderland class IV, V, or VI injury, respectively),^{13,14} with little or no chance of spontaneous recovery of “useful sensory function.” At 4 months after surgery, those patients who exhibit moderate to severe hypoesthesia (response only to pain) and those with significant dysesthesias (spontaneous or stimulus evoked) who have shown little or no improvement since injury should expect no further spontaneous improvement. In fact, pain may become intractable if left untreated. If pain is temporarily abolished by local anesthetic block of the IAN, there is hope of reduced pain following nerve repair surgery.^{15,16}

In general, patients are candidates for surgical repair of the IAN if they have significant objectively measured sensory dysfunction (anesthesia, moderate or severe hypoesthesia) and bothersome symptoms (numbness, pain, hypersensitivity) that interfere with common everyday orofacial functions¹⁷ and that the patient finds unacceptable (Table 35-1). Indications for and contraindications to microneurosurgery are listed in Tables 35-2 and 35-3, respectively. Patients who are not candidates for microneurosurgery may benefit from nonsurgical treatment (see below).

Principles of Microneurosurgery

The technical requirements and principles of peripheral nerve surgical repair in other areas of

Table 35-1 Sensory Symptoms of Inferior Alveolar Nerve Injury and Interference with Orofacial Function

Symptom(s)	Interfere(s) with
Numbness	Eating, drinking
Loss of stimulus	Shaving
localization, recognition	Washing
Tingling, crawling, itching	Toothbrushing
Burning	Placing makeup, lipstick
Pain (stimulus evoked or spontaneous)	Kissing and other oral sexual activity
Hypersensitivity	Playing wind musical instruments
	Sleep
	Mental concentration

Table 35-2 Indications for Microneurosurgery

Observed (open) nerve severance
Anesthesia > 12 wk (3 mo)
Severe hypoesthesia, not improving > 4 mo
Dysesthesia, temporarily abolished by local anesthetic nerve block, > 4 mo
Symptoms and/or loss of function unacceptable to patient

Table 35-3 Contraindications to Microneurosurgery

Dysesthesia not abolished by local anesthetic nerve block
Improving sensation
Sensory deficit or orofacial dysfunction acceptable to patient
Central neuropathic pain
Metabolic neuropathy (eg, diabetes mellitus)
Medically compromised patient (poor healing potential, anesthetic risk)
Excessive delay (probably > 12 mo) after injury

the body apply to the orofacial region as well.^{18–20}

Microsurgical repair of the IAN requires general endotracheal anesthesia, a sterile operating field, adequate exposure and access, magnification, good hemostasis, removal of pathologic tissue and foreign material, proper alignment and coaptation of proximal and distal nerve stumps, and suturing without tension. Appropriate timing of the operation is important when nerve repair surgery is delayed after the injury (see above).

Microsurgical operations on the IAN may be lengthy (2–5 hours). General endotracheal anesthesia must be maintained at an adequate depth to render the patient motionless while delicate maneuvers are completed on the IAN, which is generally 1 to 2 mm in diameter. Catheterization of the urinary bladder is necessary to prevent bladder distention from urine formation caused by adequate intravenous hydration. Protection against deep venous thrombosis is provided by alternating compression hose on the lower extremities.

A sterile operating field is needed to reduce the incidence of infection whether transoral or transcutaneous access is selected. Harvesting and transfer of autogenous nerve grafts or placement of alloplastic nerve tubes is susceptible to infection if contaminated by virulent bacteria. Nerve donor sites and other extraoral locations must be protected from contamination by oral or hospital nosocomial flora. Preoperative intravenous antibiotics reduce the risk of intraoral and extraoral infection.

The IAN may be exposed by either a transoral or a submandibular approach (Figure 35-5). Obviously, the transoral approach is already established when the nerve is injured during a mandibular ramus osteotomy. However, transoral access and visualization are often less than ideal and may compromise the surgeon's ability to achieve a desired level of technical excellence in repairing the IAN. For injuries of the IAN posterior to the first molar, I prefer the submandibular approach for closed injuries that are being explored subsequent to the time of injury. Access and visualization are far superior via the submandibular approach when the

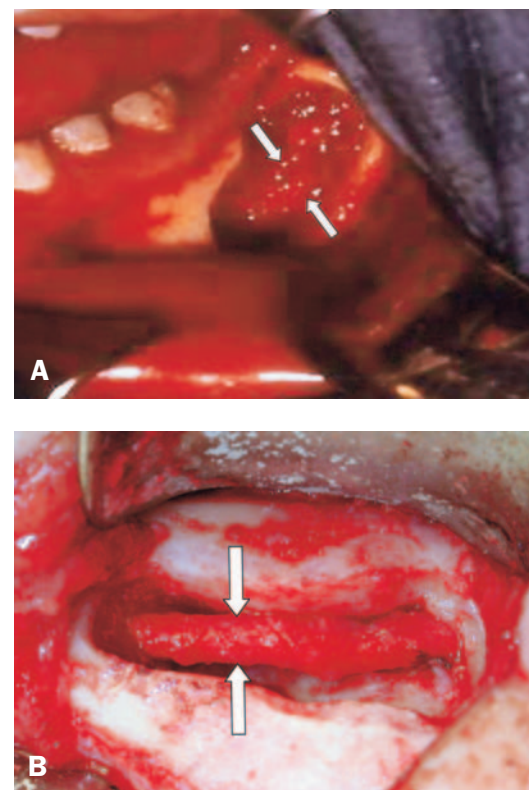


FIGURE 35-5 Surgical access to the inferior alveolar nerve (IAN). A, The inferior alveolar canal (arrows) is exposed in the molar area of the left mandible through a transoral incision. Lateral cortical and cancellous bone is removed with a high-speed drill, small osteotomes, and curets. B, The left IAN (arrows) has been exposed through a submandibular incision. When the IAN injury is in the posterior body or ramus of the mandible, visualization and access for instrumentation (especially placing nerve grafts and suturing) are superior to those possible transorally.

inferior alveolar canal is located closer to the inferior border of the mandible than the external oblique ridge and more medial rather than just beneath the lateral cortical plate of the mandible. The submandibular incision is placed in a natural skin crease or parallel to natural skin tension lines approximately 1½ to 2 fingerbreadths beneath the inferior border of the mandible. A plastic closure of the incision is accomplished under magnification. Steroids (2–5 mL of 2% triamcinolone) are injected into the incision margins of patients at high risk of hypertrophic scars or keloids. These maneuvers reduce the risk of injury to the mandibular branch of the facial nerve and

produce an inconspicuous surgical scar in most patients (Figure 35-6).

After the IAN is exposed through the osteotomy (transoral) or a window in the lateral mandibular cortex is created with the high-speed drill, small osteotomes, and curets (submandibular), visualization is enhanced by placing self-retaining soft tissue retractors and by positioning and immobilization of nerve ends by an assistant surgeon. Magnification of the IAN (1–2 mm diameter) is provided by surgical loupes, the operating microscope, or a headheld microscope. Customized loupes of 2.5 to 5 power are used during identification, dissection, and mobilization of the nerve limbs from surrounding scar tissue and bone; removal of scar tissue, neuroma, or other abnormal material; and when placing sutures intraorally, where access for the operating microscope may be compromised, particularly in the posterior body and ramus of the mandible. The microscope, with its capability for greater magnification, facilitates dissection within the nerve and placement of sutures in some situations.

Hemostasis is essential for good visualization of the operating field and to minimize the formation of scar tissue during postoperative healing. Bleeding is controlled by placing the patient in the reverse Trendelenburg position, controlling the blood pressure by the anesthesia team, placing bone wax over nutrient vessels in cancellous bone, and injecting local anesthetic containing epinephrine to minimize capillary oozing (Figure 35-7).

Once the IAN is exposed, adjacent scar tissue, bone, or foreign material (eg, internal fixation screws) is removed (external decompression) (Figure 35-8). The epineurium may be incised axially over the injured area and the internal nerve structure examined for interfascicular scarring, which is carefully removed (internal neurolysis)

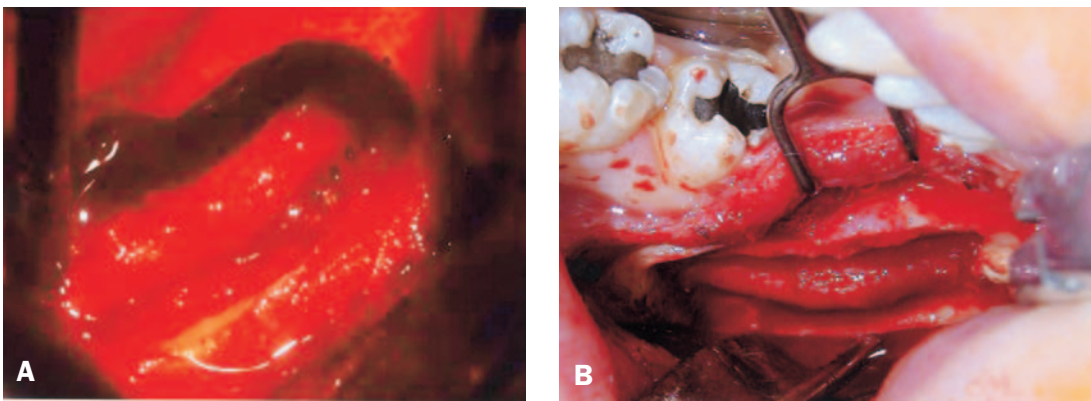


FIGURE 35-7 Control of bleeding during microsurgical repair of the inferior alveolar nerve (IAN) under general endotracheal anesthesia. A, Excessive oozing of blood from mandibular cancellous bone around the left IAN; blood pressure is 145/80 mm Hg. B, Oozing is controlled after blood pressure is lowered to 95/60 mm Hg by deepening the plane of general anesthesia and placing the patient in a reverse Trendelenburg position.

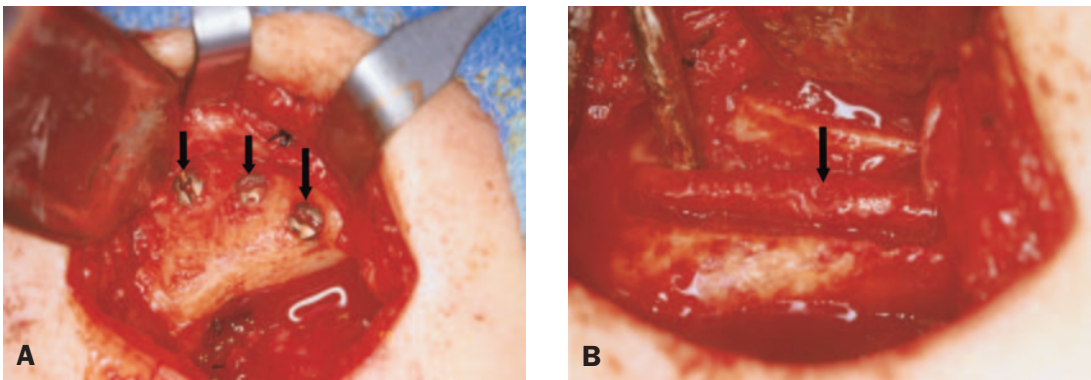


FIGURE 35-8 Decompression procedure on the right inferior alveolar nerve (IAN). A, Three internal fixation screws (arrows) placed in the mandibular ramus after sagittal split osteotomy. The patient had postoperative sensory dysfunction (pain, hypoesthesia). B, Right IAN decompressed by unroofing the inferior alveolar canal and removing the three internal fixation screws. Notice the site of penetration (arrow) of the IAN by one of the screws.

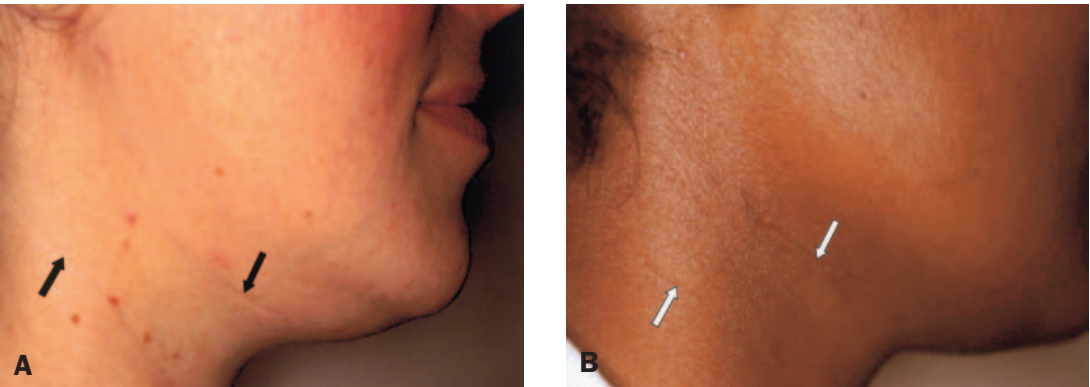


FIGURE 35-6 Inconspicuous surgical scars from submandibular incisions. A, Caucasian female 12 months after a submandibular approach to her right mandible (upper right arrow) for reconstruction of the inferior alveolar nerve (IAN) with an autogenous right great auricular nerve (GAN) graft (incision, left arrow). B, African American female 13 months after a submandibular approach to the right mandible (upper right arrow) for reconstruction of the IAN with an autogenous right GAN graft (incision, lower left arrow).

(Figure 35-9). Atraumatic microsurgical technique and good hemostasis are essential to minimize reformation of scar tissue during the healing period. Internal inspection of the nerve may reveal discontinuity of one or more fascicles (partial nerve severance). Excision of a proximal stump neuroma or a neuroma-in-continuity is done, and the proximal and distal nerve ends are

débrided of any abnormal tissue until viable fascicles are visualized (Figure 35-10). If the surgeon is providing immediate repair of an IAN injury, the above steps will not be necessary. The nerve stumps are mobilized and advanced, if possible, to approximation without tension. The coapted nerve ends are secured with tension-free fine (8-0, 10-0) sutures (neurorrhaphy) of nonreactive

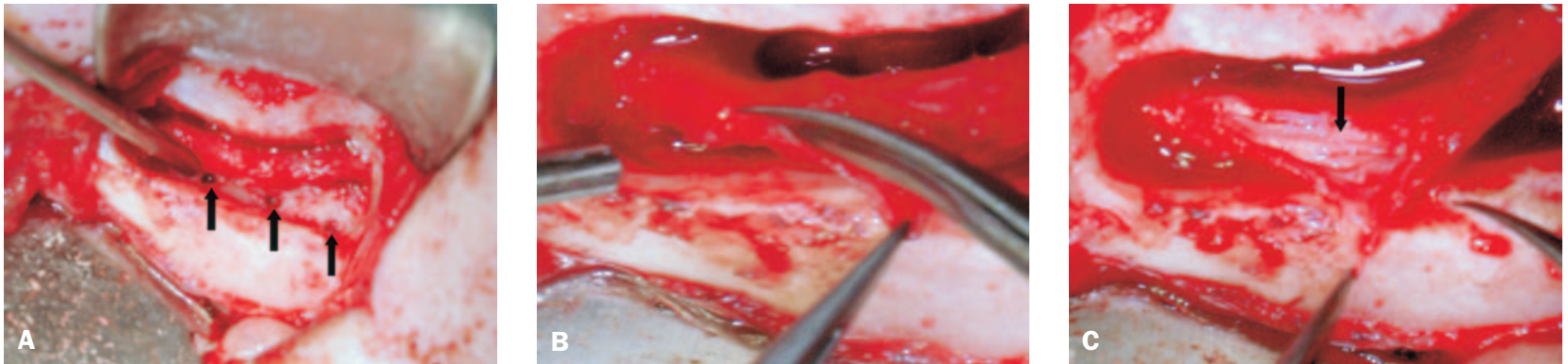


FIGURE 35-9 Internal neurolysis of the left inferior alveolar nerve (IAN). *A*, The IAN has been decompressed by removal of internal fixation screws (arrows point to screw holes) and unroofing of the inferior alveolar canal. *B*, The first step of internal neurolysis: the thickened epineurium of the IAN is opened axially with microsurgical scissors. *C*, The epineurium has been opened, and individual fascicles of the IAN can be seen (beneath the arrow). Each fascicle can be inspected for injury, and surrounding scar tissue can be removed.

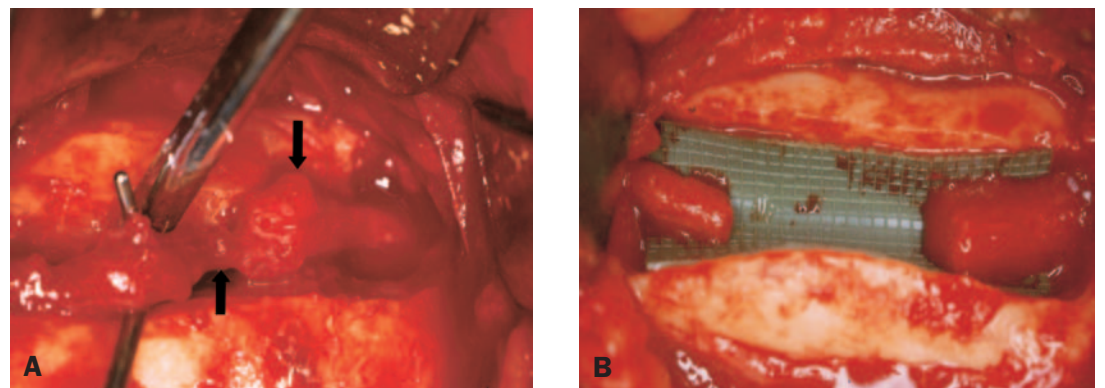


FIGURE 35-10 Preparing the injured inferior alveolar nerve (IAN) for repair. *A*, Discontinuity defect of the left IAN with the proximal nerve stump containing a neuroma (*upper arrow*). There is a thin fibrous stalk (*lower arrow*) containing no nerve tissue that connects the proximal and distal (supported by nerve hook) nerve limbs. *B*, The proximal stump neuroma has been excised, and scar tissue has been removed to expose viable fascicles in the proximal and distal nerve stumps. There is now a gap between the proximal and distal nerves.

material (ie, nylon) placed through the epineurium only (Figure 35-11). If subsequent DO is to be performed, the nerve is surrounded by an alloplastic nerve tube (collagen, polyglycolic acid), which extends distally beyond the injury site for a distance greater than the anticipated mandibular elongation. The nerve tube is sutured only to the epineurium of the proximal nerve stump, which allows the distal nerve limb to slide distally (anteriorly) within the nerve tube as distraction of the mandible is accomplished. Hopefully, the nerve gap created by DO will be bridged by axons

sprouting from the proximal IAN stump and guided by the nerve tube (entubulation) to axonal tubules of the distal nerve and then to continue growth at 0.5 to 1.0 mm/d to sensory end-organs in the lower lip, chin, gingiva, and tooth pulps (Figure 35-12).
If delayed repair of the IAN is done, preferably between 3 and 6 months postsurgery, the above step (entubulation) will not be done. If the proximal and distal nerve stumps are able to be approximated without tension, a neurorrhaphy is completed. In the more likely scenario, a gap will

exist between IAN nerve stumps that cannot be closed without significant tension. Tension across the suture line of greater than 25 g produces a stretching effect, which may cause attenuation of blood vessels in the mesoneurium and produce ischemia, leading to necrosis at the repair site, or cause the sutures to cut through the tissues at the neurorrhaphy and the nerve stumps to pull apart, thus recreating the gap and dooming the nerve repair attempt to failure.^{21,22} An autogenous nerve graft placed between the nerve stumps eliminates tension and facilitates healing potential by acting

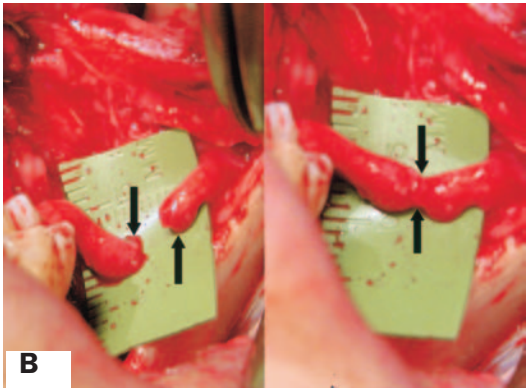
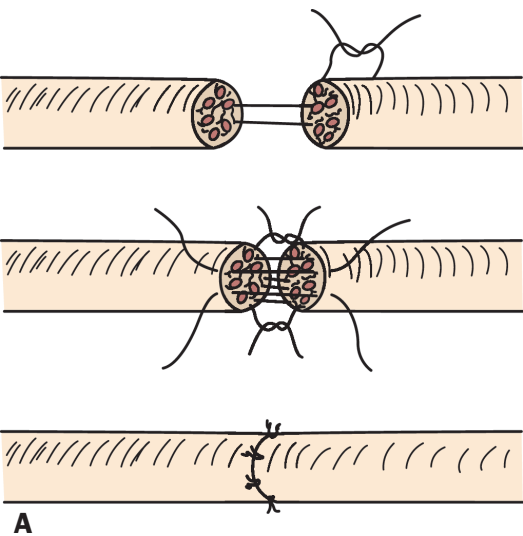


FIGURE 35-11 Neurorrhaphy: all sutures are placed through the epineurial layer only. A, Initially, a horizontal mattress stay suture is placed to approximate and stabilize the nerve ends (top). Subsequent simple interrupted sutures are placed around the epineurial margins (middle); usually, four to six sutures suffice (bottom). B, (Left) The stumps of a severed left lingual nerve (arrows) have been prepared for suturing; (right) the lingual nerve proximal and distal limbs have been mobilized by dissection and release of scar and connective tissue, brought to approximation without tension and secured with epineurial sutures (arrows). The IAN is not often able to be mobilized sufficiently to close a significant gap (ie, > 1.0 cm) without tension.

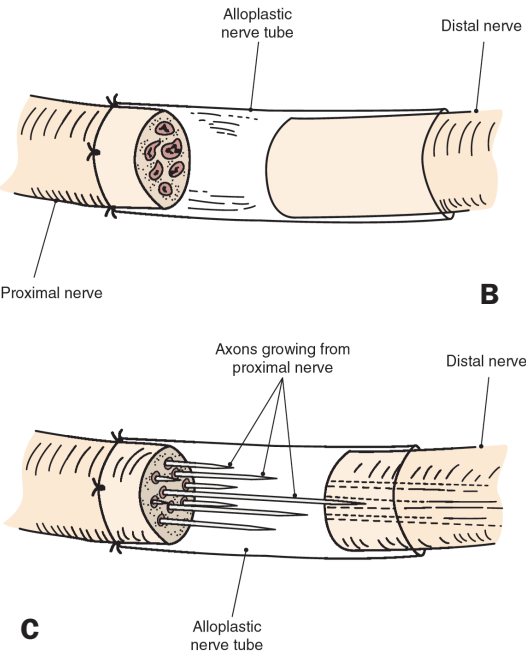
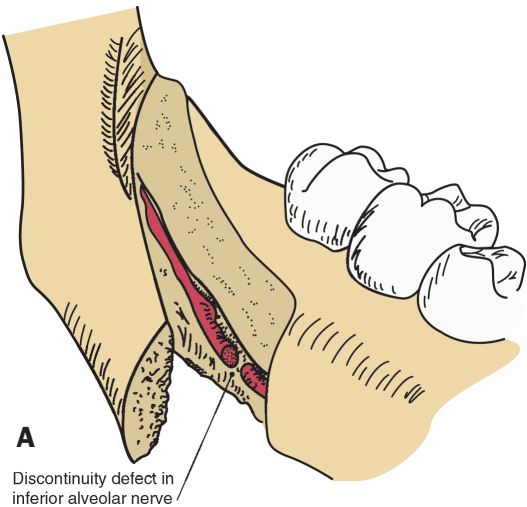


FIGURE 35-12 Management of an inferior alveolar nerve (IAN) injury that occurred during the initial sagittal split ramus osteotomy (SSRO) for distraction osteogenesis (DO). A, Injured IAN visualized in the distal segment of the mandible during right SSRO. B, An alloplastic nerve tube (collagen or polyglycolic acid) is sutured to the proximal nerve and extended beyond the distal nerve stump a distance greater than the estimated amount of mandibular elongation. C, After completion of DO, the nerve tube will serve as a conduit for axons that sprout from the proximal IAN stump and progress across the nerve gap to enter distal endoneurial tubules.

as a bridge through which proximal axonal sprouts advance to recannulate distal endoneurium (Figure 35-13). The great auricular nerve in the lateral neck and the sural nerve in the calf and ankle are common donors.²³ Proximity to the recipient site favors the great auricular nerve, whereas increased length and closer match to diameter are attributes of the sural nerve (Figure

35-14). The medial antebrachial cutaneous nerve (forearm) is an alternative favored by some.²⁴

Short-span gaps (< 1 cm) might be repaired without autogenous nerve grafting. Guided nerve regeneration^{25,26} can be accomplished successfully in selected patients using an alloplastic nerve tube as described above. The tube is sutured to the proximal and distal nerve stumps (epineurium



FIGURE 35-13 The autogenous nerve graft. *A*, The left inferior alveolar nerve (IAN) has been débrided and the nerve stump prepared for repair. There is a 2.0 cm gap. *B*, The left great auricular nerve (GAN) (cradled by nerve hook) is located just posterior to the external jugular vein (*arrow*) in the mid-lateral neck. *C*, The left IAN has been bridged by an autogenous left GAN graft (*arrows* indicate suture lines). When the graft is taken, it is 25 to 33% longer than the nerve gap to be reconstructed to account for graft contraction. The diameter of the GAN graft is seen to be less than that of the recipient IAN.

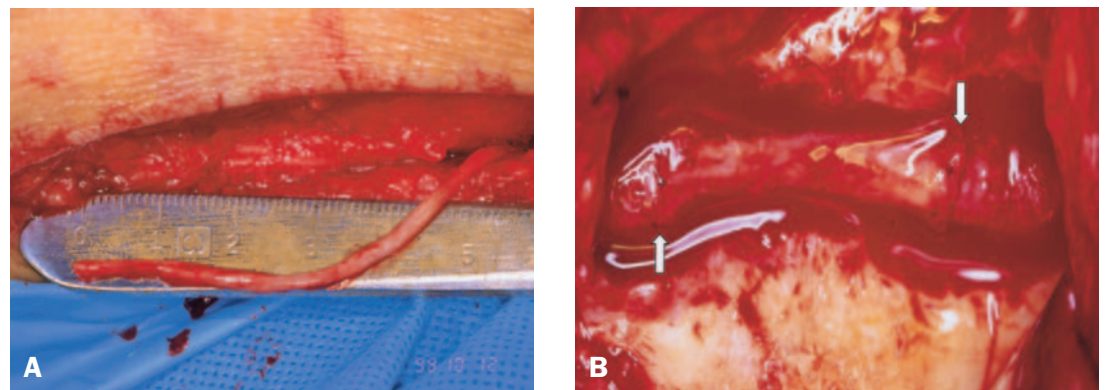


FIGURE 35-14 The sural nerve (SN) provides considerable length, extending from the popliteal fossa to the lateral ankle of the lower extremity. *A*, A left SN graft (6 cm) is taken to reconstruct the right inferior alveolar nerve (IAN). *B*, The right IAN has been reconstructed with the SN graft (*arrows*). Note the better match of diameters of the IAN and the SN graft compared with that in Figure 35-13.

only) with fine sutures, such as those for neurorrhaphy (Figure 35-15). Theoretically, entubulation isolates the nerve gap from the ingrowth of scar tissue and guides the axonal sprouts appropriately toward the distal nerve limb.

Because of infection or other postoperative complication from an ostectomy, the proximal stump of the IAN may be impossible to locate, totally replaced by scar tissue, avulsed, or otherwise unavailable for repair. If the distal stump of the IAN is viable, a nerve-sharing procedure can be performed. A sural nerve graft is used to bridge the ipsilateral greater auricular nerve and the viable IAN distal stump (Figure 35-16).²⁷

If the distal IAN is totally atrophied or otherwise unsuitable or unavailable for repair and the patient is experiencing significant pain, the proximal nerve stump is débrided of scar tissue and/or neuroma. Then a nerve-capping procedure, which may bring some relief of pain, is done by developing an epineurial flap and suturing it over the exposed fascicles with the same suture material used for neurorrhaphy. Alternatively, the proximal nerve stump may be rotated laterally and sutured to the adjacent masseter muscle (redirection procedure) (Figure 35-17). Either a nerve-capping or a redirection procedure is done on the proximal stump of a donor nerve for a

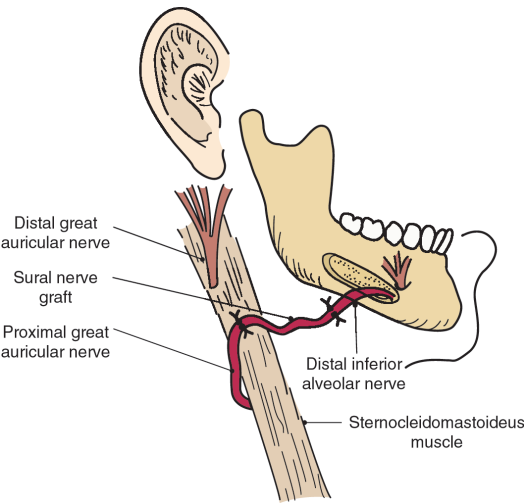


FIGURE 35-16 A nerve-sharing procedure may be indicated when the proximal stump of the inferior alveolar nerve (IAN) is unavailable or otherwise not usable. Through a subcutaneous tunnel from the lateral neck to the inferior border of the mandible, an autogenous sural nerve graft connects the proximal stump of the great auricular nerve to the distal stump of the ipsilateral IAN.

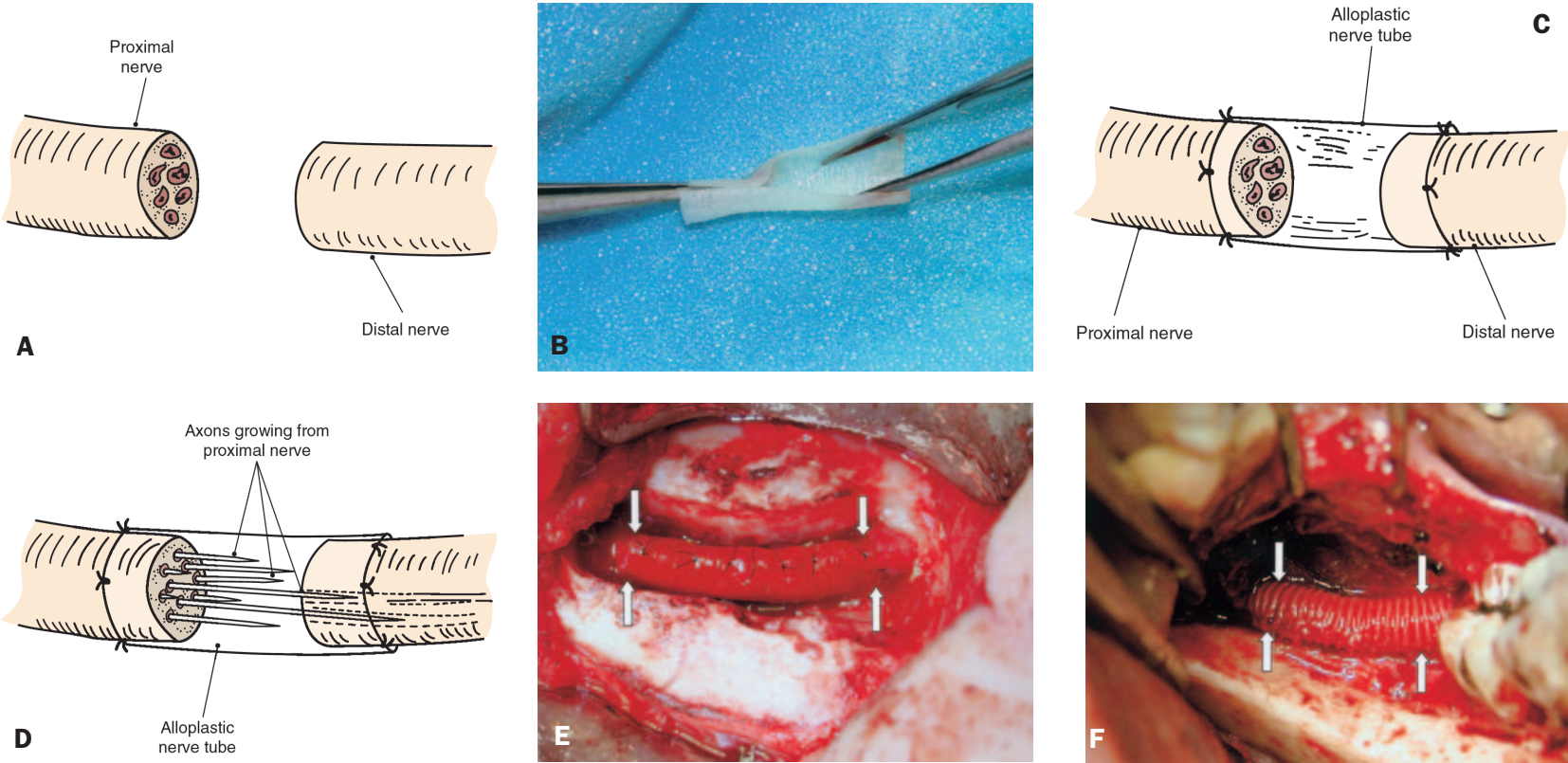


FIGURE 35-15 Guided nerve regeneration. *A*, A significant gap exists between débrided nerve stumps. *B*, A collagen nerve tube is prepared for insertion. *C*, The alloplastic nerve tube is sutured to the proximal and distal nerve stumps (through epineurium only) with fine sutures (eg, 8-0 or 10-0 nylon); usually, four to six sutures are placed in each end of the tube. *D*, Axonal growth is directed across the nerve gap by the alloplastic nerve tube; the axons enter distal endoneurial tubules and continue their growth to sensory end-organs in skin or mucosa. *E*, A collagen nerve tube (arrows) is sutured to the inferior alveolar nerve. *F*, A polyglycolic acid nerve tube (arrows) is sutured to the lingual nerve.

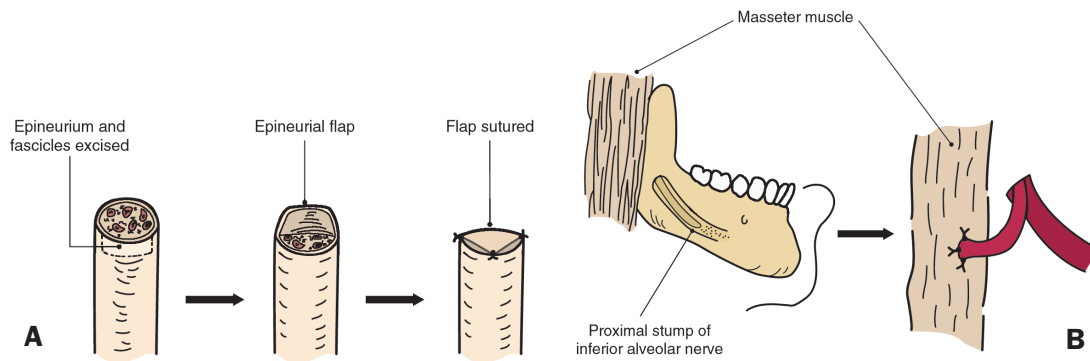


FIGURE 35-17 Management of the painful nerve stump. A, Nerve-capping procedure. Epineurium and fascicles are excised (left), and enough epineurium is preserved to create a flap (middle), which is folded over the exposed nerve stump and sutured with fine material (8-0 or 10-0) under magnification (right). B, Nerve redirection. The proximal stump of the inferior alveolar nerve is mobilized, rotated, and sutured to adjacent masseter muscle.

nerve-grafting procedure to reduce the risk of development of a painful neuroma in the donor site.

Results

Patients are followed with periodic NST for at least 12 months after microsurgical nerve repair or longer if their neurosensory status continues to evolve.

The immediate postoperative effect of microsurgical repair of the IAN is generally anesthesia of the ipsilateral lower lip, chin, and mandibular labial gingiva, regardless of whether there was a discontinuity defect or anatomic continuity was intact as a result of the injury. Patients are advised to return for reevaluation when sensation begins to return (often heralded by tingling, crawling, itching, or burning sensations and the ability to sense hot or cold temperature) but no later than 4 months after surgery. Estimates of the growth rate of axonal sprouts from the proximal nerve stump are between 0.5 and 3.0 mm per day,²⁸ beginning after necrotic distal axonal material has been cleared by phagocytosis, leaving intact endoneurial tubules ready to receive those new axons. Typically, following repair of a severed IAN, one may expect, on average, initial return of sensation after 4 to 7 months. As soon as sensory symptoms are reported by the patient, NST is performed to determine the presence or absence of responses. Reevaluation is done at 1- to 2-month intervals thereafter until no further improvement is recorded, generally 12 or more months after nerve repair.

Nerve injury repair results are graded using the modified Medical Research Council (MRC) scale (Table 35-4), developed and first used for hand injuries²⁹ and adapted to the maxillofacial region in the 1990s.³⁰ In my series of 666 peripheral trigeminal nerve injuries that were repaired in 599 patients between 1986 and 2005, 89 IAN injuries occurred during mandibular ramus orthognathic surgical procedures (88 after SSROs,

Table 35-4 Modified Medical Research Council Scale for Assessing Recovery of Sensory Function

Score	Assessment
S0	No recovery
S1	Recovery of deep cutaneous pain
S2	Return of some superficial pain, tactile sensation
S2+	Same as S2 + hyperesthesia
S3*	Same as S2; no hyperesthesia and static 2 pd > 15 mm
S3+*	Same as S3, with good stimulus localization and 2 pd = 7–15 mm
S4*	Same as S3 except 2 pd = 2–6 mm

2 pd = two-point discrimination.
 *Assessment score of S3 or better = “useful sensory function.”

one owing to IVO, none with DO). All patients were followed for a minimum of 1 year until their neurosensory status stabilized. A successful IAN repair was one that achieved an MRC scale level of S3 (so-called “useful sensory function”), S3+, or S4. Eighty of 89 patients (89%) achieved a final MRC rating of S3 or better. Of the nine patients who failed to achieve satisfactory return of sensation or a reduction in pain (below S3 level), the common denominators of failure were patient age greater than 40 years, time from injury to surgical repair greater than 12 months, and predominant complaint of pain, rather than numbness, with pain relieved incompletely, if at all, by preoperative local anesthetic block of the injured nerve.

After 1990, all patients in my series performed daily sensory reeducation exercises postoperatively beginning after the return of responses to painful stimuli and static light touch and continuing for at least 1 year. These exercises, originally designed for hand injuries,³¹ help the central nervous system overcome “scrambled” input from repaired peripheral nerves with different axonal connections than before injury, regain

stimulus localization and graphesthesia, diminish subjective feelings of “numbness,” and reduce hyperesthesia in the distribution of the repaired nerve. The reader is referred to Meyer and Rath for an in-depth discussion of sensory re-education that is beyond the scope of this chapter.³²

Painful or other abnormal sensations and impaired orofacial function may persist in some patients, whether or not surgical nerve repair results in improved NST results. Performance of everyday orofacial activities, maintenance of personal relationships, and continuation of employment may be curtailed or adversely compromised. Management with pharmacologic (antidepressants, anticonvulsants, antineuralgics, local anesthetics), behavioral (counseling, psychotherapy, relaxation therapy), or physical (physical therapy, transcutaneous electrical nerve stimulation, acupuncture) modalities provides some patients with an acceptable reduction in symptoms. For a small but unfortunate group of patients with intractable neuropathic pain, a global approach by a multidisciplinary pain management clinic may assist with resumption of some activities of everyday living.

Conclusions

IAN injuries are known and accepted risks of orthognathic surgical procedures in the mandibular ramus. Although knowledge of anatomy and modifications in technique may decrease these risks in selected patients, the risk of sensory nerve injury remains. These risks should be included in the preoperative informed consent discussion with an orthognathic surgery patient.

An open IAN injury may be repaired at the time it occurs if the surgeon possesses microsurgical skills and appropriate instrumentation and assistance are at hand. Postoperative recognition of a closed IAN injury and documentation by a standardized neurosensory evaluation should be done promptly and repeated periodically until a decision can be made, usually by 3 to 4 months postinjury, regarding the need for microsurgical nerve repair. The best results following microsurgical repair of an IAN injury occur when the nerve is repaired less than 6 months following injury by an experienced surgeon, the patient is under 40 years of age, and the patient’s principal symptom is numbness rather than pain.

Patients who continue to suffer neuropathic pain following nerve injury repair may benefit from pharmacologic, behavioral, or physical treatment or by management in a multidisciplinary pain clinic. Continued research and clinical experiences will add to our knowledge of neuropathophysiology and develop new approaches, surgical and nonsurgical, for the management of the nerve-injured patient.

Overall, the risks of IAN injury and the persistence of unpleasant or undesirable sensory dysfunction in the orthognathic surgery patient are quite small. Most significant IAN injuries can be successfully repaired and useful sensory function restored, if done in a timely fashion by a skilled microsurgeon. This information should be made known to the patient prior to orthognathic surgery. The risk of nerve injury should not be considered a deterrent to this surgery. The benefits of improved masticatory function, enhanced facial esthetics, and increased self-esteem or self-worth following orthognathic surgery far outweigh the risk of IAN injury.

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Treatment Goals for Obstructive Sleep Apnea

Richard M. Dasheiff and Richard Finn

Patients seek medical attention because of chronic poor and nonrestorative sleep. The primary symptom is excessive daytime sleepiness (EDS). However, EDS is not specific to sleep apnea, and two-thirds of people with polysomnographic evidence of obstructive sleep apnea (OSA) do not have sleepiness. When EDS is caused by OSA (not merely associated with it), then it is called obstructive sleep apnea syndrome (OSAS). Since the apnea-hypopnea index (AHI) is used to determine the presence of OSA, it has mistakenly been used as a surrogate for EDS. The AHI is easy to measure and thus gets thrust into the limelight. It has even assumed the role of arbitrator for determining the specific treatment modality, for example, continuous positive airway pressure (CPAP) versus oral appliance versus upper airway surgery. The primary treatment goal, EDS, must be confidently assessed before and after treatment. If the patient reports no further EDS after treatment, a follow-up polysomnogram to document the AHI is unnecessary. Treatment goals should not be set to prevent or treat any cardiovascular disorders based solely on the presence of OSA. Patients with OSAS should be treated primarily to reduce their EDS, with cardiovascular end points as secondary goals. Patients with “refractory” hypertension and OSA should be treated to evaluate its effectiveness in reducing the blood pressure. Treatment goals for OSA directed at reducing surgical or hospital-based morbidity and mortality are presently beyond the scope of community standard medicine.

Definition of OSA and OSAS

OSA is a diagnosis made by a test, usually a polysomnogram, but also from simpler procedures, such as nocturnal oximetry. OSA subsumes both obstructive apneas (total absence of airflow) and hypopneas (approximately 50% reduced airflow) as both presumably have the same consequences on sleep and the associated medical pathophysiologies. An AHI is the averaged number of apneas and hypopneas per hour over the entire sleep time during the study.

OSA is extremely prevalent in the general population (possibly as high as 30% using an AHI > 5), but so is sleepiness, at 40%.¹ In the Sleep Heart Health Study ($N = 6,440$), one-third of subjects with an AHI < 5 (no OSA) had EDS.² Yet only half of the subjects with an AHI > 30 (severe OSA) had EDS. Thus, as it pertains to sleep apnea, EDS has a highly unsatisfactory false-positive and false-negative rate.

When EDS is caused by OSA, it is called OSAS. Treatment is necessarily directed to patients with OSAS because these are the people who usually present for medical care. However, increasing numbers of patients are now being referred who do not have OSAS, or even OSA, with the hope of treating an associated medical condition with CPAP.

Background

Health care providers enter into a contract with patients through various avenues. Some patients directly seek care, whereas others are referred by other health care providers. Knowing the patient's and the consulting provider's agenda is crucial to effective care.

What Does the Patient Want?

Often the patient wants a solution to poor and nonrestorative sleep resulting in EDS. Concomitantly, it may be only a desire to appease a spouse so that the bed partner can get a good night's sleep without the patient's snoring, kicking, and frequent awakenings. Children are usually seen because the parents or the school is concerned about quality of life (QoL) or scholastic issues.

What Does the Provider Who Requests the Consultation Want?

The provider implicitly wants to diagnose and improve the health of the patient. However, often specialty-specific concerns are superimposed; for example, a cardiologist hopes to reduce recurrent bouts of congestive heart failure or an ophthalmologist hopes to prevent worsening of ischemic optic neuritis.

What Does the Patient Need?

Again, implicitly, the patient needs an accurate diagnosis and treatment directed to improve health and QoL. This may be in concert with what the patient and/or requesting provider wants. The treating health care provider's first charge is toward the patient's interest, based on best medicine.

Do No Harm

Treatment decisions always require a balance of risks and benefits. This analysis should be based on actual data that cover both sides of the equation. However, pertinent information may be lacking, obscure, or controversial, leaving the practitioner unable to move beyond past dogma. For example, CPAP treatment originally used only unheated, unhumidified air. Some patients with special upper airway conditions or living in extremely temperate zones and dry climates seemed to benefit from heat and/or humidity. Without consideration of the extra equipment maintenance involved, heated humidity became standard practice in many communities for all patients. However, heated humidity does not improve the intrinsic effectiveness of CPAP³ and may⁴ or may not³ improve patient compliance but has been reported to increase the incidence of respiratory infections by 3- to 10-fold.⁵

Treatment-Specific Modalities

Improvement or complete resolution of OSA can be accomplished through various medical and surgical modalities (eg, weight reduction, oral appliance, upper airway surgery—phase I, maxillomandibular advancement—phase II, CPAP, tracheostomy). Restoring QoL, and reversing or preventing associated adverse health consequences, should theoretically be modality independent. However, the present literature is biased toward studies using CPAP as the treatment modality, and positive results are generally attributed to CPAP alone. It may be that in addition to the elimination of obstructive apneas, the effects of positive airway pressure on lung

physiology, intrathoracic pressure, and sympathetic tone provide an additional and key component to the efficacy of treating OSA, but this is only speculation at this time. Of all of the treatment modalities, only weight reduction would seem to provide a wider range of health benefits to the patient (ie, treating OSA and obesity-related morbidities), and the other modalities should be viewed as providing treatment for OSA only.

History

Sleep disorders and sleep apnea are not new, and the negative impact on QoL has been documented as far back as Hippocrates in 440 BC:

And I see men become mad and demented from no manifest cause, and at the same time doing many things out of place; and I have known many persons in sleep groaning and crying out, some in a state of suffocation, some jumping up and fleeing out of doors, and deprived of their reason until they awaken, and afterward becoming well and rational as before, although they be pale and weak; and this will happen not once but frequently.

Sleep apnea was first reported independently in 1965 by groups in France and Germany.^{6,7} At the time, no one in the United States believed that it was a real disorder. This was another example of the now classic NIH (not invented here) syndrome. Additionally, it would be another 16 years before CPAP was introduced as a treatment. In 1972, Christian Guilleminault, a French neurologist and psychiatrist, joined the new Stanford Sleep Program, and sleep apnea came to America.

That same year, Dr. Guilleminault consulted on an obese, sleepy, and severely hypertensive 10-year-old boy.⁸ He made the diagnosis of OSAS and recommended a tracheostomy. The attending physicians refused to consider any treatment other than medication. With delay and considerable controversy, he eventually received his tracheostomy, with accompanying resolution of the hypertension and EDS.

Best Medicine

Community standard practice is often defined as what a prudent health care provider would do. Expert care is based on a critical review of published evidence. The difficulty is in the definition of “critical.” Although reviews and recommendations from evidence-based medicine have become commonplace, the general medical community has been slow to accept the results.⁹ A similar disconnection affects its counterpart, cost-effective medicine.

When the literature reports a comparison between two treatments, one treatment is generally more effective, better tolerated, or better preferred by the patient. This is usually supported

by a statistically significant probability (p) value. Often the treatments are separated by only a few percentage points. Consider a study of QoL and blood pressure control in which it was found that captopril was better than propranolol.¹⁰ It would be incorrect for clinicians to assume that the “winner” is the only treatment that should be offered to their patients. Medicine is not a political election in which the majority rules. Best care dictates that the physician has knowledge of all treatment modalities and will tailor the best treatment for the individual patient.

Although there are multiple, effective modalities for treating sleep apnea, the “clear” winner in the literature and in practice is nasal CPAP. Some studies report that oral appliances are preferred over CPAP,¹¹ whereas other studies reverse the percentages.¹² Battle lines are often drawn between medical and surgical specialties. If treatment modalities are chosen as winners, then patients will be the losers.

Health care providers are sophisticated enough to know the difference between statistical significance and clinical significance. We are aware that we must go beyond both measures in making a good case for our analysis and conclusions in this chapter. Our caveat to the reader is the magnitude of the evidence (or lack thereof) in support of a particular recommendation. In 1941 (before the advent of randomized clinical trials), it took only six patients to prove the worth of penicillin.¹³ Also, it was not difficult to conclude the usefulness of insulin for diabetics. But in our present era of randomized clinical trials, tens and hundreds of millions of dollars can be spent on a treatment without clear evidence of which treatment, if any, is effective. We bias our review by only using evidence of sufficient magnitude that would likely convince all providers.

Consults to Sleep Program

Table 36-1 shows selected unedited narratives submitted to Sleep Medicine in response to Check Off Best Reason for Consult.¹¹ This is what physicians actually request of their consultants and represents valid scientific data for analysis. Sometimes these narratives are cryptic, and the intent and prejudices of the provider must be inferred. Surprisingly, patients sometimes came to their appointment without knowing the reason for their referral. Ultimately, if the consultant cannot accurately determine the agenda, good care and successful outcome will fail.

Several themes can be deduced. Sometimes the consultant is a surrogate for the bearer of difficult news (eg, lose weight, restrict driving). Most of the time, the goals of better sleep and relief of nocturnal apneas are coopted with aims to improve specific medical conditions. For example, it is hoped that a depressed patient not

responding to antidepressants will sleep better on CPAP, or there will be reduced hospital admissions for patients with recurring congestive heart failure. Unfortunately, many of these goals are unrealistic. Reading through these consultation notes also points out the high failure rate for CPAP, which has been repeatedly documented to be 20 to 30%.^{14–16}

General Treatment Goals

The goals of treating OSA must be realistic in terms of patient compliance and medical outcome. Both are still generally underappreciated. For example, is it better to treat a patient with an AHI of 50/h with nasal CPAP that reduced the AHI to zero but who after 3 months uses it 4 hours per night, 3 nights per week or to prescribe an oral appliance that reduced the AHI to 10/h, which is used 7 hours per night, 6 nights per week? Clinical outcome data do not exist to help with this type of choice.

Treatment of OSAS is rarely successful by a one-time intervention because, unfortunately, there is a high failure rate for all modalities when assessed both acutely and in the long term. The health care provider should therefore be prepared to offer the patient alternate modalities. Equally important is to plan a staged approach to maximize success. For example, nasal CPAP will be unsuccessful in patients with significant nasal patency problems who are mouth-breathers. Full face masks have significant interface problems and work for only a small percentage of patients. Therefore, after a diagnostic polysomnogram, patients may benefit from surgical treatment to remove polyps, have nasal septal repairs, or address other upper airway obstructive pathology. After adequate healing (typically 6 weeks), nasal CPAP titration can be done and nasal CPAP issued.

OSAS is a chronic condition that in most patients does not spontaneously remit and will require years, if not a lifetime, of treatment. It may take considerable time to reach the most efficacious and enduring treatment modality. Although patients and referring providers typically press for treatment as soon as possible, treatment is not a medical emergency.

Excessive Daytime Sleepiness

Treatment of OSAS is directed to either keep the airway from collapsing, bypass the obstruction (tracheostomy), or increase the airway diameter through weight loss. Such procedurally oriented treatment goals can frequently be achieved but are ultimately measured against the patient's clinical symptoms. The preeminent symptom is EDS.

EDS can be a QoL issue, an economic issue, and a legal issue. If patients are too sleepy to drive,

Table 36-1 Consultant Requests for Services by Sleep Medicine
Pt had testing done outside the VA but he cannot use the CPAP; states it wakes him up and scares him. So he is not using anymore. Please appt for eval for other options.
Pt on CPAP but unable to sleep at night. Having trouble adjusting to mask and now afraid to go to sleep.
Pt with hypertrophic cardiomyopathy and episodes of “blacking out.” Unclear if syncope vs falling sleep. Previously dx OSA (early 1990). Need to confirm this and treat OSA if needed; I need to clarify if he needs a defibrillator or not.
Sleep apnea. States he doesn’t eat right and doesn’t intend to change. Has 2 donuts and chocolate milk for breakfast. Laughs when I discussed need for central weight loss.
During bronch. pt noted to desat to low 80s once asleep and snoring with apneic spells. Dynamic collapse of oropharynx and central airways noted during bronch.
Compulsive eating disorder, obese, uncontrolled diabetes - chronic MOOS c/o of tight throat laying down (Pickwick)
58 yo AAM < c/o snoring and also panic attack at nights due to finding himself gasping for air when wakes up suddenly for the past 15 yrs. Urgency: within 1 mo.
Pt has prior sleep study and was told he is “borderline for need of CPAP”; however, recently has experienced increase in apneic spells [per wife] has associated wt gain [312 lbs] and awakens with food in his mouth. Not sure if he needs an updated sleep study or if can go by most recent one. Appears to need expedited appt. Thanks!
Pt request sleep study and CPAP. Pt had one in past but felt it did not work b/c he is a mouthbreather and felt that the nasal prongs did not work
Pt has need to have fingerprints done for his security job/pt has been rejected because his fingerprints are inadequate and needs dr signature to determine fingerprint ridge deterioration and/or finger malformation that would tend to make this individual’s fingerprints unclassifiable. Refer to sleep clinic for equipment.
Emergency room - sleep consult, admitted for pleurisy
=Emergency room - sleep consult, presented with BRBPR, dx hemorrhoids
Amb care vesting. 50 yo man with no signif PMH who comes in for eval of OSA. Pt reports that he lives in Corpus Cristi but that he drives a truck for a living and is frequently in Dallas. He was told by one of his colleagues who shares a sleeping compartment with him that he has pauses in his breathing and stirs a lot in his sleep. Pt denies any daytime sleepiness unless he truly hasn’t gotten his 8 hours of required sleep. He has never fallen asleep while driving.
He says he is having excessive drowsiness and falls asleep while visitng with his girlfriend and while driving his job requires freq driving.
Presents to urgent care for: referral for sleep study to evaluate for sleep apnea. Reports feeling tired during the day and wife is complaining of loud snoring at night.
Pt with morbid obesity, HTN, DM, restrictive lung disease on home O ₂ . Please evaluate for benefit of CPAP in alleviating dyspnea.
Pt drinks 2½ gallons of tea and 2 pots of coffee in day; also some alcohol every other day. He was diagnosed with sleep apnea 5 years ago but cannot tolerate his machine, so never uses it.
Patient with daytime sedation, chronic insomnia; wife says he snores loudly and gasps for air at night and wakes up, has PTSD and MDD and used to have HTN, is mildly overweight. Please rule out sleep apnea complicating everything. Patient is truck driver and falls asleep on the steering wheel, thanks.
Morbidly obese patient was undergoing cardiac cath. When he laid down his airway collapsed and he stopped breathing. Needs emergency CPAP.
BRBPR = bright red blood per rectum; CPAP = continuous positive airway pressure; DM = diabetes mellitus; HTN = hypertension; MDD = major depressive disorder; OSA = obstructive sleep apnea; PMH = past medical history; PTSD = post-traumatic stress disorder; VA = Veterans Administration.

the law prohibits them from driving. Documenting this in the medical record is advisable. The most obvious and most serious issue for sleepy people is traffic accidents. It is necessarily intuitive that anyone with OSAS is at increased risk of traffic accidents. This association has been reported in the literature and further suggests that treatment with nasal CPAP reduces this risk.¹⁷ It is likely that even in the absence of convincing evidence, health care providers would feel compelled to treat these people, especially in this era of defensive medicine. However, as recently as 1997, evidence to link OSAS and road traffic accidents was still inconclusive,¹⁸ and the best study to date is only marginally better.¹⁹ Although many

studies summarily report the association as if it were a fact, it has been exceedingly difficult to factor out confounding variables such as age, alcohol use, obesity, annual mileage, shift work, sleep debt, and social activities in these epidemiologic studies, and no randomized clinical trials are likely to be performed.

Does OSA Cause EDS?

The answer is not an unequivocal yes. As mentioned earlier, patients diagnosed with OSA can be very sleepy with a low AHI or have no EDS by any measure with a high AHI. Patients with OSA frequently have comorbid sleep disorders such that even when the AHI is reduced to

zero, their periodic limb movement disorder, restless leg syndrome, shift work, or obesity-hypoventilation syndrome will still leave them sleepy. This can call into question whether the comorbid condition alone produced the EDS. For example, all obese people are mistakenly thought to have OSA. In fact, only 55 to 75% of obese patients were found to have OSA.^{20,21} Conversely, 35% of morbidly obese patients who had no polysomnographic evidence of OSA had significant EDS.²²

There is an obvious selection bias in the literature and in our clinical practice for identifying and treating patients with subjective sleepiness. This does not have to imply that OSA never causes EDS, only that EDS is not an invariable consequence of OSA. In a very comprehensive and critical review of the literature, Wright and colleagues concluded that “evidence from epidemiological studies suggests that possibly the only significant adverse effect of obstructive sleep apnoea is daytime tiredness and a reduction in attention.”²³ Epidemiologic studies can point out only an association, not a causality. The apparent reversal of EDS with treatment in many patients, although of clinical utility, also is not hard scientific evidence that OSA is necessary and sufficient to cause EDS. Even sham nasal CPAP (placebo) has been shown to reduce EDS,²⁴ adding support to the contention that a response to CPAP should not be used to confirm a diagnosis of OSAS.

How to Measure EDS

To the non-sleep expert, sleepiness is sleepiness, something we all know from personal experience and can see in others. However, for objective science, this quality must be measurable and quantified. Alas, there is no agreement on how to do this. A measure that seems to work well with one disorder (eg, Multiple Sleep Latency Test [MSLT] for narcolepsy) fails when applied to another disorder (eg, OSA). What is worse is that different measures neither correlate with one another nor correlate with other clinical measures.²⁵⁻²⁹ Interviewing the patient and spouse, parent, or significant other provides as good a measure as a written evaluation with the Epworth Sleepiness Scale or polysomnographic measures such as the MSLT or Multiple Wakefulness Test (MWT), or a simple index such as the AHI, or a complex test such as the Psychomotor Vigilance Test.

Of particular relevance to our topic is whether the AHI provides a measure of sleepiness in patients with OSAS and whether retesting (via a polysomnogram) after treatment of OSAS provides any useful information. OSA (but not OSAS) is given a grade of mild, moderate, or severe based solely on the AHI. Polysomnographic factors such as the duration of the apneas or extent of the hypoxemia provide a subjective measure of the clinical severity of OSA but have

not been incorporated into a valid scale. In fact, the AHI is a poor measure of EDS³⁰ and should not be used in isolation in making a treatment decision. Additionally, electrophysiologic variables such as the AHI are not good predictors of improvement with therapy.³¹

Despite its one-dimensionality, the AHI is easy to measure and thus gets thrust into the limelight. It has even assumed the role of arbitrator for determining the specific treatment modality, for example, CPAP versus oral appliance versus upper airway surgery. The literature is unduly biased toward excluding any modality other than CPAP for high AHIs because it makes the implicit (but unjustified) assumption that AHI is the only factor to treat in OSA. However, treatments for OSA can reduce the AHI but not EDS, and vice versa. The present emphasis on AHI has unduly influenced recommendations from randomized clinical trials. An example is a study that showed equal efficacy between CPAP and an oral appliance for resolving EDS but recommended CPAP.³²

Does Treating OSAS Reduce EDS?

Most review articles conclude that treatment of OSAS reduces EDS. However, qualifications on who the patients are, how EDS is defined, which treatment modality was used, and how long after treatment patients were assessed are all critical for a proper interpretation. By definition, patients with OSA are not sleepy, only those with OSAS. Subjects enrolled in studies tend to have severe OSA and marked EDS. Generalization to patients with mild OSA or mild EDS may not be applicable. Methodologic problems and statistical effects such as regression to the mean are frequent confounders.

Leaving aside all of the other variables, let us review which treatment modalities have an effect on EDS associated with OSAS. Babar and Quan concluded that all treatment modalities “have disadvantages, and none, except for tracheostomy, are uniformly effective.”³³ The evidence for tracheostomy is akin to that for the initial use of penicillin: it has an immediate and dramatic effect.³⁴

The evidence of all randomized controlled studies shows that CPAP reduces EDS in patients with moderate to severe OSA up to 6 weeks, and patients with mild OSA do not receive this benefit.^{25,32} Wright and colleagues concluded from a review of the literature that CPAP was more effective than placebo for improving EDS when either the Epworth Sleepiness Scale or the MWT was used as the measure of sleepiness but not the MSLT (which measures the tendency to fall asleep rather than the ability to remain awake).²³ Although the statistical significance was good, the magnitude of the effect was modest. Jenkinson and colleagues performed a study with a true sham CPAP treatment, and used the Epworth

Sleepiness Scale, the MWT, and a QoL questionnaire to measure sleepiness.²⁴ They found that CPAP reduced EDS compared with sham nasal CPAP, but there was a significant placebo effect.

There are many types of oral appliances, with mandibular advancement being the most common, followed by tongue repositioning. A review by Lim and colleagues concluded that an oral appliance improves subjective sleepiness compared with controls.¹² These effects tended to last at least a year. A review by Ferguson showed sufficient success to recommend oral devices as first-line treatment for mild and moderate OSA.¹¹

Combining all surgical treatments (excluding tracheostomy) as one type of treatment is unwarranted but frequently done, with an emphasis on the AHI rather than EDS. When viewed individually, every treatment has a positive effect on EDS, although small numbers, uncontrolled series, and biased patient selection will dilute the credibility of the results. Powell recently reviewed the surgical literature and continues to find support for phase I and II surgeries in reducing or eliminating EDS.³⁵ Cillo and colleagues found that even a combined open rhinoplasty with spreader grafts and uvuloplasty significantly and for the long term reduced EDS in veterans with all severity levels of OSAS.³⁶

All presently acceptable treatments for OSAS reduce sleepiness in the majority of patients for variable periods of time. As the primary treatment goal, EDS must be confidently assessed before and after treatment and at long-term follow-up. *If the patient reports no further EDS after treatment, a follow-up polysomnogram to document AHI is unnecessary.*

Quality of Life

Like so many outcome measures, QoL seems straightforward until you try to measure it. Despite any *p* values for a particular treatment effect, if the patient (or significant other) does not perceive any physical or mental benefit, the treatment is not useful and does not provide any improvement in QoL. A reduction in EDS, more daytime energy, a feeling of well-being, fewer visits to the doctor for health issues, enhanced sexual performance, and many other variables can contribute to QoL. For example, in a study using a mandibular advancement splint for OSA, the AHI was reduced from 32 to 18, which was statistically significant at $p < .01$.³⁷ Although the patients still had OSA, the only noteworthy outcome was the number of separately sleeping couples who were reunited after therapy—a QoL issue. Some studies and reviews have concluded improved QoL after the treatment of OSAS,^{38,39} whereas other have not.²⁵ The field of QoL research is particularly contentious because despite any negative published finding, physicians will not accept the premise that treating disease and

alleviating discomfort fail to improve the patient's QoL.

One goal for treating OSA or OSAS is improvement in the patient's quality of life. The simplest way to assess this is to ask the patient.

Cardiovascular Disease

An association between two prevalent disorders, sleep apnea and cardiovascular disease, is not unexpected, especially when obesity is presently thought to be linked to both. Nevertheless, sleep apnea is assumed to produce adverse cardiovascular consequences owing to the increased negative intrathoracic pressure, hypoxemia, and increased sympathetic nerve activity produced by the apneas and hypopneas.^{40–44}

Studies to untangle the many overlapping comorbidities found in the typical overweight male study populations are at a disadvantage unless there is a particularly large effect. There are few studies in children, women, and thin men. Critical reviews between 1997 and 2001 found evidence for only weak associations and no causality between OSA and hypertension, arrhythmias, ischemic heart disease (IHD), left ventricular hypertrophy, stroke, pulmonary hypertension, and right-sided heart failure.^{18,45}

Hypertension

The Wisconsin Sleep Cohort ($N = 704$) was a prospective, population-based study that found an association between increasing severity of OSA (as measured by the AHI) and hypertension.⁴⁶ In the Sleep Heart Health Study, isolated systolic hypertension was not associated with OSA, but systolic/diastolic hypertension was associated with OSA for subjects under 60 years old.⁴⁷

In 1997, the Sixth Report of the Joint National Committee on the Prevention, Detection, Evaluation, and Treatment of High Blood Pressure by the National Heart, Lung, and Blood Institute, National Institutes of Health, listed the top three causes of refractory hypertension as smoking, obesity, and sleep apnea.⁴⁸ In the most recent Seventh Report of the Joint National Committee released in 2003, sleep apnea had moved up to the number one cause of identifiable (not just refractory) hypertension.⁴⁹ Although the primary treatment modality is medication, weight loss for obese patients was also recommended. Nothing was specifically proposed as a treatment for the patient with sleep apnea.

Evidence to move from association to causality can be supported but not proven by prevention or reversal of hypertension with an effective treatment for OSA. CPAP has been the treatment of choice to investigate this possibility. Many studies have reported positive effects that chronic CPAP use is associated with improvement in hypertension, echocardiographic parameters, and congestive heart failure.^{50–55} Conversely, others

believe that CPAP is an unqualified success in treating EDS yet are unconvinced of its efficacy in correcting cardiovascular consequences.³⁹ A typical study can show a large effect (20 mm Hg systolic) sustained for 6 months in 12 patients.⁵⁶ All studies suffer from various methodologic problems, which reduce the scientific validity that OSA is the sole cause and CPAP the sole reason for the hypertension and its resolution. Although CPAP takes center stage, weight reduction as a method to treat OSAS is also reasonably effective in reducing hypertension.^{49,57}

The upshot of all of this attention on sleep apnea has been an escalation of opinion, often in a pro-and-con format, with no unequivocal evidence-based studies to support either side. In fact, the two opposing camps often end up making the same conservative recommendations, as in the pair of articles addressing whether all sleep apnea patients should be treated.^{58,59} Both acknowledge the increasing evidence that cardiovascular risk has been associated (but not causally linked) to OSA and therefore suggest that it might be prudent to treat patients with OSA of any degree even if they have no EDS. Considering the magnitude of the problem, the resources to accomplish this goal would need to be immense.

Heart Disease

A Swedish group followed patients with established coronary artery disease and compared the long-term outcome between the groups who had OSA and those without OSA.⁶⁰ The OSA group had an increase in the primary end points of death, cerebrovascular events, and myocardial infarction. Another study in men reported that severe OSA significantly increases the risk of fatal (death from myocardial infarction or stroke) and nonfatal (nonfatal myocardial infarction, nonfatal stroke, coronary artery bypass surgery, and percutaneous transluminal coronary angiography) cardiovascular events compared with healthy individuals even after adjustment for potential confounders.⁶¹ CPAP treatment was associated with a lower risk. However, a Canadian group addressed the key issue of whether treating OSA with CPAP reversed the associated increased morbidity or mortality of IHD and found that the answer was no.⁶² The encouraging results were that patients on CPAP with OSA but without IHD reduced their consumption of health care resources. However, patients with OSA plus IHD continued to need increasing amounts of health care. Treating OSA with CPAP did not help their heart disease. In the Sleep Heart Health Study, which followed over 6,400 subjects, those with AHI values that were considered normal or only mildly elevated showed modest to moderate effects of OSA on a range of cardiovascular end points.⁶³ Subjects with moderate to severe OSA did not show increased cardiovascular morbidity.

Pulmonary Arterial Hypertension

Primary or idiopathic pulmonary arterial hypertension (PAH) is a diagnosis of exclusion with a poor prognosis. Considerable effort is therefore made to identify a potential etiology that may be amenable to treatment. Anecdotal reports have claimed tracheostomy or CPAP as absolutely necessary for successful treatment of secondary PAH in patients who have OSA. Frequently cited articles mention finding OSA in patients with PAH but that obesity is more likely to be a contributing factor than sleep-disordered breathing.^{64,65} The review by Wright and colleagues found no convincing association between PAH and OSA.¹⁸ Evidence-based clinical practice guidelines proposed in 2004 by the American College of Chest Physicians conclude that the prevalence of OSA is low in PAH and that other risk factors, such as left-sided heart disease, parenchymal lung disease, nocturnal desaturation, and obesity, contribute more than OSA.⁶⁶ Further, treatment of preexisting OSA with CPAP may only lower pulmonary artery pressures when the degree of PAH is mild.

Conclusion

In the last decade, an increasing number of studies have looked at the association between OSA and cardiovascular disease. The evidence seems most compelling that OSA contributes to persistent systolic/diastolic hypertension in some patients independent of other risk factors and that successful treatment of OSA (CPAP, tracheostomy, weight loss, and probably other modalities) will improve control of the hypertension. We agree with Malhotra and White that the association between OSA and other cardiovascular disorders is still incomplete.⁶³ Treatment goals should not be set to prevent or treat any of these cardiovascular disorders based solely on the presence of OSA. Patients with OSAS should be treated primarily to reduce their EDS, with cardiovascular end points as secondary goals. Patients with refractory hypertension and OSA should be treated to evaluate its effectiveness in reducing the blood pressure.

Other Medical Conditions

The potential impact on health from OSA and OSAS is leading to studies spanning all fields of medicine. Even now, the list is long enough to deserve an entire textbook. For example, OSA has been implicated in detrimental metabolic consequences associated with decreased insulin sensitivity,^{67,68} activation of inflammatory processes,^{69,70} increased oxidative stress,⁷¹ increased matrix metalloproteinases,⁷² and intravascular thrombosis.⁷³ Chronic CPAP use has been associated with improvement in inflammatory processes,^{70,74} insulin sensitivity,^{75,76} and thrombotic tendency.⁷⁷

Disorders that are not traditionally associated with sleep, such as Cheyne-Stokes respirations, dyspnea on exertion, and obesity-hypoventilation syndrome, are nonetheless being treated by nocturnal CPAP in the hope of some benefit, despite the lack of any evidence-based literature. For example, nocturnal CPAP and bilevel positive airway pressure have been used to treat daytime hypercarbia in obese patients who also have OSA. In a retrospective study, the PaCO₂ decreased from 54 ± 7 to 49 ± 7 mm Hg.⁷⁸ Numerous study design flaws require caution in assessing this small but statistically significant effect.

Sometimes there is confusion over the order of cause and effect such that the goals of treatment cannot be preventive or curative. For example, although sustained anoxia will cause brain injury and neuronal death, does this also occur from the repetitive hypoxia in OSA? Studies in mice suggest that this can occur.⁷⁹ Therefore, it might seem reasonable to treat everyone with OSA to prevent brain damage. Yet the evidence is just as convincing that preexisting neuronal abnormalities may form the basis for altered neuromuscular control of the airway, which predisposes the individual to OSA.⁸⁰ Until much better research is available, treatment goals of OSA cannot be justified in this area.

Various ophthalmologic findings are being associated with OSAS, including eyelid hyperlaxity⁸¹ and floppy eyelid syndrome,⁸² with a case report of its reversal.⁸³ Ischemic optic neuritis or retinopathy is a serious condition, and the recurring bouts of nocturnal hypoxia associated with OSA make treatment with CPAP or any other effective modality seem desirable. However, in the Sleep Heart Health Study, after adjustment for age, body mass index, hypertension, diabetes, and other factors, the presence of retinopathy was not associated with sleep apnea.⁸⁴ Nevertheless, this does not preclude the possibility that eliminating OSA in patients with retinopathy would not be beneficial, but this awaits study.

Headaches are nearly universal, so an association with OSA or OSAS would seem certain. Headache is a common finding in both OSAS and insomnia patients.⁸⁵ Present studies, such as a report of increased incidence of morning headaches in patients who completed an overnight polysomnogram compared with the general public⁸⁶ or a lower than expected incidence of OSA in patients with headache referred to a specialist,⁸⁷ do not constitute adequate epidemiologic studies to draw any conclusions. Case-control studies show a high incidence of OSA in patients with cluster headaches, although no trials have been published on the effects of treating the OSA in these patients.^{88,89} Surprisingly, there is no literature associating sleep apnea and migraine.

Sleep disturbance is common in patients with gastroesophageal reflux disease (GERD). The primary treatment modality is medication,

which can be effective 50% of the time.⁹⁰ When reflux is controlled, the quality of sleep is improved. The association between OSA and GERD is therefore important, especially in refractory patients. Morse and colleagues could find no objective correlation between OSA and GERD in their patient population.⁹¹

The present state of evidence-based literature does not support interventional treatment of OSA or OSAS by any modality to prevent or ameliorate the myriad of medical conditions that have been presented in this section. Although health care providers have good intentions and individual patients may benefit, population medical guidelines for ordering studies and instituting treatment remain unsupported.

Anesthesia and Preoperative Screening

There can be several ways to spur research and advance care in medicine, and the malpractice lawsuit is one such way. Successful lawsuits have been based on cases such as the patient with OSA on CPAP who did not bring CPAP to the hospital, died 24 hours postoperatively, and whose autopsy was negative; the patient diagnosed with OSA who was never treated, who died 24 hours postoperatively, and whose autopsy was negative; and the patient with OSA and uvulopalatopharyngoplasty who died 24 hours postoperatively and whose autopsy was negative. The basis for these lawsuits has been the assertion that physicians were negligent in the care of patients who either had a preexisting diagnosis of OSAS or a presumed diagnosis of OSA. This has caused the profession to reevaluate perioperative procedures and treatment goals.

The natural history of patients with OSAS and the positive effects of aggressive treatment (eg, tracheostomy) have been reported for the last two decades.^{34,92} A critical review in 1997 of the sleep apnea literature concluded that age, hypertension, and body mass index had the largest and most significant effects on excess mortality.¹⁸ The AHI was not predictive of excess deaths owing to heart or lung causes.

However, patients given sedatives or analgesics, which can depress neuromuscular control of the airway, are at increased risk of aspiration or respiratory arrest. Although patients with OSA might seem to be at even greater risk than non-OSA patients, there is little evidence-based literature to support this contention.⁹³ A critical review of ambulatory surgery found that although patients with OSA were at increased risk of difficult tracheal intubation, the likelihood of airway obstruction and apnea following ambulatory surgery was unknown.⁹⁴ In a retrospective, case-control study, adverse postoperative outcomes occurred at a higher rate in patients with OSAS undergoing hip or knee replacement.⁹⁵

However, another case-control study found no difference in adverse events between controls and OSA patients receiving nonotorhinolaryngologic outpatient surgical procedures.⁹⁶

The increasing concern about managing patients who have OSA induced, unmasked, or exacerbated by perioperative procedures and treatments is leading to published guidelines in the absence of evidence-based data.^{97,98} Anesthesiologists and surgeons who manage patients for OSAS or bariatric surgery are already sensitized to the risks. But what about patients undergoing non-upper airway surgery? Professional societies are recommending screening of all elective surgical candidates for OSA. Unfortunately, stating such goals in the absence of a simple and effective method puts the health care provider at risk.

The categories for screening include (1) patients with diagnosed OSA receiving treatment; (2) patients with diagnosed OSA who are not on treatment (pending, refused, noncompliant, failed); (3) patients with OSA who have not been diagnosed; and (4) patients who do not have OSA at home but develop it under conditions of illness, medication, or anesthetic agents. Screening might include a history of snoring, frequent arousals, and daytime somnolence; a questionnaire on sleepiness; and a physical examination (obesity, a large neck). Not only do these and other traditional measures have an unacceptable false-positive and -negative rate for adult males, they also misidentify the risk in women and children and thin males. Requiring a polysomnogram or even overnight pulse oximetry for every elective surgery is impractical. Even when a patient is identified with OSA, it is unknown what additional measures would prove successful in preventing excess morbidity and mortality. Even careful monitoring in the recovery room and hospital floor has proved ineffective.^{99–101}

Treatment goals for OSA directed at reducing surgical or hospital-based morbidity and mortality are presently beyond the scope of community standard medicine.

Future Directions

The high prevalence of OSA and the interest shown by patients and private corporations will drive technologic advances in the diagnosis and treatment of OSA and OSAS. Some of these will actually help with the decisions about treatment goals, whereas others will bring new issues to the fore and make older ones moot. For example, wireless electronic networks and powerful computing systems are starting to be used to monitor and direct treatment to acutely ill patients.¹⁰² Someone who does not have OSA but develops it during an admission from conditions such as myocardial infarction or stroke might benefit from having OSA diagnosed and treated in the hospital.

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Airway-Compromising Mandibular Hypoplasia in Neonates

Kevin S. Smith

The use of distraction osteogenesis (DO) for neonates (less than 3 months old) with mandibular hypoplasia has been helpful in relieving airway and feeding difficulty. Surgical approaches to managing upper airways in Pierre Robin sequence (PRS) infants have included tracheostomy, glossopepy, hyomandibulopexy, tongue-lip adhesion, circummandibular wire, and subperiosteal release of the floor of the mouth. Tracheostomy has been considered by many to be the gold standard of treatment in airway difficulties, but it has not been without its detractors. There are potential complications, such as granulation tissue formation, innominate artery hemorrhage, pneumothorax, tracheal tube obstruction, cricoid cartilage injury, and accidental decannulation. Long-term problems include delayed development of speech/language skills, pulmonary infections, behavioral problems, and problems with parent-child social interactions.

Neonates with airway-compromising retrognathia usually have a nonspecific working diagnosis of PRS. PRS has been described with both syndromic and isolated, nonsyndromic variations. In the isolated, nonsyndromic variation, the clinical triad of cleft palate, micrognathia, and glossoptosis and the associated feeding difficulties and airway disturbances are the only malformations noted. In the syndromic variation, the clinical triad and associated feeding and airway maladies are only part of a greater number of malformations associated with a genetic or developmental syndrome. The syndromic associations include Stickler syndrome, velocardiofacial syndrome, fetal alcohol syndrome, Treacher Collins syndrome, distal arthrogryposis, and chromosome 6q deletion.

Upper airway obstruction in infants has been associated with failure to thrive, gastroesophageal reflux, hypoxia, hypercapnia, cor pulmonale, neurologic impairment, and death. Mortality rates reported have varied widely, from 5 to 65%, and death has been thought to be a consequence of the combined effects of malnutrition, exhaustion, pulmonary sepsis, and/or sudden cerebral anoxia. The mortality rate has been reported as 22.8% in PRS associated with a syndrome but only 5.9% in nonsyndromic PRS patients.¹

Indications

The indications for DO in the neonate should be relatively rigid and straightforward. Severe airway compromise is the main indication for the use of DO in neonates. The neonate should be airway compromised to the point that the consideration of a tracheostomy has been made. The threshold for making the decision may be lowered during the winter months as the potential for upper respiratory infection increases. An example would be a neonate who is born in the month of November and on initial evaluation is able to deal with airway compromise by positional control of lateral and prone sleeping positions. This same infant who has an upper respiratory tract infection 3 months later may have severe airway compromise in any position. This infant could now be in mortal danger if certain care is not taken. This is especially true in a family situated in a rural area without immediate specialized care.

The second indication is feeding difficulty in the infant (greater than 3 months old). This indication may be controversial but has come about through the observation of the feeding ability of multiple airway-compromised infants. In virtually all of the DO cases performed by this author, the feeding in distracted neonates was essentially normalized. The neonates who had cleft palates still had to use some form of cleft feeder. The timing of mandibular advancement in this situation may be variable owing to the possible placement of gastric tubes.

Evaluation

The nature and mechanisms in airway obstruction in PRS patients are multifactorial, and the treatments proposed reflect this. There is great variability in the severity of airway compromise and in the treatments designed to manage the airway compromise.

The evaluation should take place as rapidly as possible, and early surgical intervention should be accomplished if possible. The age range of neonatal patients when DO was performed at our institution was 10 to 68 days, with a mean age of

26.4 days ($n = 10$). Additionally, DO was performed on two infants over 6 months of age, with an average age of 245 days.

The neonate should be stabilized and airway temporization accomplished prior to beginning any studies. Initial studies include a polysomnographic (PSG) study if possible. This can usually be done at the bedside with or without oxygen, and the neonate may be awake or asleep. If the neonate requires intubation or a laryngeal mask airway, a sleep study cannot be obtained. The PSG study, if done, will give information as to the severity of the obstruction and desaturation levels in an objective manner.

Thorough evaluation of the airway aimed at determining the mechanism of the obstruction should be performed prior to initiating long-term management. Sher used flexible fiber-optic nasopharyngoscopy to identify the nature of airway obstruction in patients with craniofacial anomalies, including PRS.² The author reported on 53 cases of PRS and categorized the type of obstruction found in relation to the primary diagnosis (syndromic vs nonsyndromic). In this study, 53.5% of the patients had type I obstruction, 20.8% type II, 9.4% type III, 9.4% type IV, and 1.9% other. The four types of obstructions were described as follows:

- Type I: Posterior movement of the dorsum of the tongue to the posterior pharyngeal wall. This is primarily an anteroposterior-positioning problem.
- Type II: Posterior movement of the tongue, but the contact is with a long soft palate or cleft palatal tags, which then impinge on the pharyngeal wall.
- Type III: The lateral pharyngeal walls move medially, causing them to approximate.
- Type IV: Circular or sphincteric constriction of the pharynx, with movements occurring in all directions.

This information is helpful in predicting if the distraction surgery will be helpful in the resolution of the airway compromise. It is of the utmost importance that an airway evaluation is

performed, not only for the above reasons but also to evaluate the subglottic airway. This evaluation has cancelled the impending distraction surgery in two cases when subglottic stenosis was found to be the cause of the airway compromise. If DO would have proceeded, certain failure to resolve the airway obstruction would have resulted.

High-quality three-dimensional computed tomography (CT) and the fabrication of a stereolithographic model are recommended. The use of stereolithographic models for presurgical evaluation and planning has been shown to decrease the operative time.³ ClearView Stereolithographic Models from Medical Modeling Corporation, Golden, CO were used; vital structures, such as the inferior alveolar nerve and the developing tooth buds, are visible in these models, and the location of the corticotomy was planned with knowledge of these structures. The distraction appliance can be prebent to fit the mandibular contours present in each case, which significantly reduces operating time and improves accuracy. In most instances, the turnaround time for the fabrication of these models was 24 to 48 hours so as not to delay surgery.

Along with a thorough systemic evaluation, additional consultations would include genetics, cardiology, pulmonology, neurosurgery, and other members of the craniofacial team as needed.

Biologic Foundation

The use of DO in neonates for mandibular advancement is a sound treatment in that the majority of cases that have had endoscopic evaluation show a type I or II airway. In these situations, the advancement of the mandible will, in most instances, resolve the compromising position of the tongue base. A video of the tongue position prior to and after mandibular DO advancement shows tongue repositioning from the dorsal side of the soft palate to a normal floor of the mouth resting position. This change in position normalizes the airway and feeding. The likely failures of DO would include neonates with Treacher Collins syndrome and other craniofacial anomalies, including malformation of the ramus, condyle, and glenoid fossa. These types of cases need additional bone stock that may not be satisfied by DO alone.

Several authors have observed the relief of upper airway obstruction by the use of mandibular DO. Long-term results describe stabilization of the airway obstruction and better feeding by the infant.^{4,5}

Advantages and Disadvantages

The advantages of DO for these patients would include the ability to avoid a tracheostomy

or progression to decannulation if the patient already trached. Normalization of oral feeding is also an advantage. The benefits of these changes would be physical and psychosocial. The physical benefits are evident, but long-term follow-up will be needed to determine the longitudinal effects on dentition and mandibular growth. The longest follow-up for neonates treated with DO by our institution is 5 years, and clinical and radiographic evaluations show that there is no growth disturbance in the mandible and all primary teeth are developed and erupted normally. This patient does not have any airway or feeding difficulty as recorded by subjective parental observation and objective PSG evaluation postsurgically. The interaction and socialization of toddlers may progress more readily without the tracheostomy. The reluctance of some medical professionals and certainly the insurance companies to partake in quality of life issues probably underestimates this psychosocial benefit.

Technique

Once the stereolithographic models have been obtained, the surgery is planned. The location of the corticotomy is planned to avoid vital structures and to allow distraction in the desired direction (Figure 37-1). The distraction appliance is adapted and cut to fit the stereolithographic model at this time and then is sterilized prior to placement at the time of surgery. The vector of the appliance is parallel to the inferior border of the mandible.

We are currently using the KLS Martin L.P. (Jacksonville, FL) micromandibular internal distraction appliance (Figure 37-2), which is available in 10, 15, and 20 mm distraction lengths. The appliances are contoured on the stereolithographic models so that they are as parallel as possible. Access to the surgical site is via a submandibular approach. It is not advised to try



FIGURE 37-1 Stereolithographic model fabricated from computed tomography for preoperative surgical planning.



FIGURE 37-2 A 20 mm micromandibular distraction device produced by KLS Martin.

the intraoral route to place the device. This will compromise paralleling the devices with each other and the inferior border. Additionally, many other surgeons have called our institution after failed attempts via the intraoral approach. The appliance is positioned but not secured. The corticotomy is marked on the mandible as was predicted on the stereolithographic model, the appliance is removed, and an incomplete corticotomy is performed with rotary instrumentation using a small-diameter taper fissure bur (701). The corticotomy is extended to all aspects of the mandible that can be readily visualized. The distraction appliance is then anchored to the mandible using 1.0 mm bone screws, avoiding vital structures, as seen on the stereolithographic model. Do not use self-drilling screws as the neonate mandible will splinter. Always drill the hole for screws using the appropriate drill. The appliance is activated, and then the corticotomy is completed using osteotomes if needed. Often activation of the appliance alone will complete the corticotomy (Figure 37-3). The

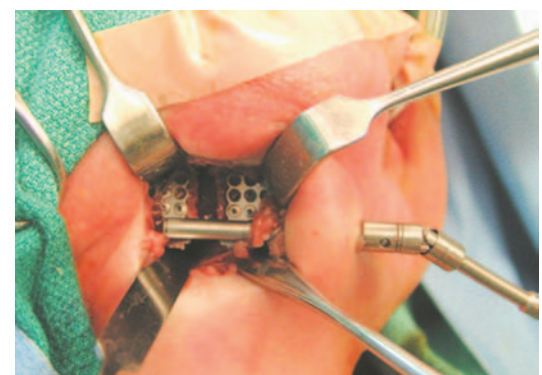


FIGURE 37-3 Mandible is exposed from a submandibular approach. The prebent distraction device is placed appropriately and the mandible is marked, the appliance is removed, and superior, lateral, and inferior border corticotomy is performed. The corticotomy is carried on the medial side of the mandible as far as can be visualized. The appliance is now returned and secured to the mandible. Do not use self-drilling screws. The appliance is then activated, and the mandibular corticotomy is now completed with osteotomes. The appliance is now returned to its original position.

drive mechanism is a simple screw in an antirotation slot drive and exits the skin via a small submental incision. The drive shafts are available in various lengths to accommodate transcutaneous placement and are available in rigid and flexible designs. One-dimensional DO is obtained with this appliance. The submandibular incision is closed in an aesthetic manner (Figure 37-4).

Owing to the rapid healing responses of neonates, our center does not use a latency period. The distraction process is initiated immediately and proceeds at a faster rate than for adults. Our treatment protocol is as follows:

1. No latency period
2. 1.5 mm DO per day
3. Three activations per day (0.5 mm per activation)
4. Minimum of 6 weeks' consolidation after DO is completed
5. Removal of the device through the original incision with aesthetic closure

Morbidity

In our experience, three complications have occurred. The first was a minor wound infection that was readily treated with antibiotics and wound care. Scarring was seen on all cases but was not significant owing to its submandibular placement. The third complication occurred when the endotracheal tube was inadvertently dislodged during the course of the surgery. This occurred after general anesthesia had been

initiated and just as the surgery was about to begin. During efforts to reintubate the patient, the patient suffered barotrauma to both lungs when being ventilated using a face mask. The surgery was stopped, and tracheostomy and chest tubes were placed to treat the bilateral pneumothorax. The patients' lungs were allowed to heal, and, subsequently, the distraction appliance was placed uneventfully; the infant ultimately was decannulated, had resolution of apnea, and resumed normal feeding.

Facial scarring, sensory and motor nerve damage, major hemorrhage, and loss of fixation should be considered the highest occurring risks. There has not been one case of a lack of consolidation at our institution. In fact, most patients show exuberant bone growth to the extent of bone covering the mesh panel of the distractor.

The dentition has been disrupted in very few of the patients, with malpositioned impacted teeth being the most common problem (Figure 37-5).

Cost

The cost of treatment is approximately \$10,000 in undiscounted fees (prior to insurance write-offs). This includes surgical fees and appliances. Billing should include mandibular osteotomies and a code for an unlisted procedure to account for the time to care for the DO and care of the consolidating mandible. At this time, there are no current procedural terminology (CPT) codes for DO. The hospital costs for these types of cases are high owing to intensive neonatal care, CT scans, and the number of specialists involved during the treatment of a neonate.

The comparison of alternative surgical intervention (DO) with tracheostomy shows that the costs of tracheostomy care, supplies, nursing, and doctor visits quickly outpace the cost of the alternative surgery if successful. Cohen and colleagues

reported that the breakeven point occurred at 6 months.⁶

Case Report

A below-normal birth weight neonate with no diagnosed genetic abnormalities underwent consultation by the cleft craniofacial team for acute airway obstruction. The airway was stabilized with an oral airway. The clinical examination was consistent with a working diagnosis of PRS. The mandibular hypoplasia and glossoptosis caused airway collapse, and a tracheostomy was being considered (Figure 37-6). A polysomnogram showed an apnea index of 8.3 with supplemental oxygen. Preoperative CT scans were made, and a



FIGURE 37-6 A 25-day-old neonate lateral profile view prior to distraction osteogenesis. A surgical airway was elected owing to the inability to fiber-optically intubate the neonate.



FIGURE 37-4 Postoperative view of a patient showing paralleling of the right and left appliances as closely as possible.



FIGURE 37-5 Changes in dentition include malpositioned teeth.

stereolithographic model was obtained. The neonate was taken to the operating room for DO at 25 days. A surgical airway was established after noninvasive attempts made to secure the airway failed.

Bilateral DO devices were placed through submandibular incisions, and after 1 cm DO had occurred, the bone was allowed to consolidate for 6 weeks. During this consolidation time, the neonate had started normal feeding with a Haberman nipple (Figure 37-7). The DO devices were



FIGURE 37-7 Post-distraction osteogenesis lateral profile view 10 days after surgical placement of distractors.

removed, and the neonate was decannulated while in the operating room at 6 weeks post-DO and was again discharged without respiratory difficulty and normal feeding. A postoperative polysomnogram at 9 months showed an AI of 0.0. The 4-year follow-up showed good continued growth (Figure 37-8) and no interference with



FIGURE 37-8 A 48-month postoperative lateral profile view shows a slightly concave profile that is consistent with Class III malocclusion. No airway or swallowing difficulty was noted at the examination.

tooth formation and eruption. The occlusion is slightly Class III.

Conclusion

The use of DO for the airway-compromised neonate is a valuable tool in the resolution of breathing problems. It may also be an option for correction of eating or swallowing difficulty in the retrognathic neonate. Thorough evaluation needs to take place prior to the surgical decision to distract to ensure that noninvasive methods will not yield positive airway changes. Meticulous attention to the placement of the devices and the resultant vectors need to take place to prevent open bite-type malocclusions after DO is completed.

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Distraction Osteogenesis in the Management of Obstructive Sleep Apnea Syndrome

Kelly Magliocca and Joseph I. Helman

Obstructive sleep apnea (OSA) is a serious disorder that affects 2 to 4% of adults¹ and is most commonly seen in middle-aged, overweight men.² Disturbances in sleep patterns and oxygenation are considered to be responsible for the major clinical manifestations, which include daytime somnolence, systemic hypertension, and cardiopulmonary failure. The pathogenesis of OSA is incompletely understood.

Surgical options are influenced by the severity of the disease, the current state of the literature, the experience of the surgical team, and the patient's wishes. Current surgical alternatives, such as uvulopalatopharyngoplasty (UPPP), genial advancement with or without hyoid suspension (GA or GAHS), and maxillomandibular advancement (MMA), are directed at enlarging the airway dimensions and decreasing collapse of suspected anatomic sites.³⁻⁷ The effectiveness of MMA in the treatment of OSA has been repeatedly demonstrated.³⁻⁷

At our institution, any patient with multi-level airway obstruction who wishes to pursue surgical treatment of their OSA is offered MMA as their first-line treatment. The rationale for our approach is based on the results of a retrospective evaluation of our outcomes of 22 consecutive patients treated with UPPP and GAHS on whom we were able to obtain both pre- and postoperative sleep studies (19 males and 3 females) performed from 1995 to 2000.⁸ The average age of the patients was 46 years, and the average body mass index (BMI) was 31.9 kg/m². Using a postoperative respiratory disturbance index (RDI) of < 20 or a reduction in the postoperative RDI of 50% (if the preoperative RDI was initially less than 20) as a parameter of cure, we identified an overall cure rate of 26% (Table 38-1).

Similar outcomes were reported by other investigators who demonstrated minimal benefits to patients undergoing UPPP and/or GAHS⁴⁻⁹; therefore, the option of UPPP and/or GAHS

Table 38-1 Outcomes of Genial Advancement and Hyoid Suspension
Respiratory disturbance index Lowest oxygen saturation N = 22 (M = 19, F = 3) Age = 46 yr (SD = 9 yr); range 31–58 yr BMI = 31.9 kg/m ² (SD = 6 kg/m ²); range 23–46 kg/m ² Postoperative PSG = 5 mo (SD = 3 mo) Success = 26%
BMI = body mass index; PSG = polysomnogram.

should be carefully reevaluated based on the poor success rates on patients with moderate or severe OSA.

Based on retrospective data review, not all patients with OSA and/or obesity were able to achieve a cure with MMA.⁸ In a retrospective analysis of 29 consecutive patients who underwent MMA between 1996 and 2002 (25 males and 4 females), with an average age of 41 years and an average BMI of 33.2 kg/m², we identified an overall cure rate of 78.3% (Table 38-2). The preoperative and postoperative BMI remained stable. We therefore proceeded to investigate the subgroups at risk of failure, which showed that patients with a BMI of > 32 kg/m² or an RDI > 70 had an overall chance of cure of 60%, regardless of previous airway surgery. Patients with a BMI < 32 kg/m²

Table 38-2 All Patients Undergoing Maxillomandibular Advancement
N = 29 (M = 25, F = 4) Age = 41 yr (SD = 8 yr); range 16–55 yr BMI = 33.2 kg/m ² (SD = 87 kg/m ²); range 21.5–52.6 kg/m ² Postoperative PSG = 6 mo (SD = 4 mo); range 1–22 mo Success = 78.3%
BMI = body mass index; PSG = polysomnogram.

and an RDI < 70 had more than a 90% chance of cure.

The suspected limiting factor with traditional MMA was the inability to accomplish a large enough advancement. Thus, patients expected to require a large advancement of the maxillomandibular complex were projected to benefit from maxillomandibular advancement via distraction osteogenesis (MMADO).

McCarthy and colleagues were the first team to report gradual distraction of human mandibles.¹⁰ The majority of the clinical applications of osteodistraction involve lengthening of the jaws of growing patients. Transport distraction osteogenesis is a modification used in tumor- or trauma-related defects. More recently, the application has been expanded to involve lengthening of the jaws of adult patients with skeletal disharmonies as an alternative to conventional orthognathic surgery.¹¹ We propose the use of distraction osteogenesis to simultaneously elongate the maxillary and mandibular arches to enlarge the posterior airway space in adult patients with severe OSA.

Principles of Distraction Osteogenesis:

Distraction osteogenesis applies stress to a site of surgically produced bone disruption¹² and uses the body's natural reparative mechanisms to create new bone.¹³ Tissue regeneration occurs by increasing vascularity and recruiting osteoblasts.¹² During the surgical procedure, the bone is sectioned and the distraction device is applied. Distraction osteogenesis then consists of the following steps¹³:

- Latency, which represents the interval from surgery to that of the application of distraction force. During this period of 5 to 7 days, local healing occurs and a callus forms. Latency is influenced by the age of the patient;

the younger the patient, the shorter the latency required.¹³

- Distraction, the process in which gradual traction results in new bone formation (the distraction regenerate). The course is affected by the rate and rhythm (frequency) of distraction device activation.
- Consolidation is the interval in which the distraction regenerate matures after the termination of traction. Consolidation is influenced by the ability of the fixation device to stabilize the new bone formed and the length¹¹ of the distracted bone. Mobility causes disruption of the new blood vessels, bringing about the failure of the newly formed bone. Consolidation timing is related to the patient's age; the younger the patient, the shorter the healing time.¹⁴ The radiographic evaluation during consolidation is used to time the removal of distraction devices. The appearance of a cortical outline within the regenerate correlates with bone healing.¹³ Other techniques, such as ultrasonography, are also being investigated as determinants of consolidated bone.¹⁵

Responses of Oral Tissues to Distraction Osteogenesis

Bone

Four zones have been identified within the distraction gap during distraction: the central fibrous zone; a transition zone in which fibroblasts and undifferentiated precursor cells were in continuity with the osteoblasts; the zone of bone remodeling, which contains increased numbers of osteoclasts; and mature bone demonstrating evidence of compact cortical bone, which is similar in appearance to the adjacent nondistracted bone.¹⁶ Other investigators have delineated a similar classification of areas in the distraction gap.¹⁷

Temporomandibular Joint

Based on animal studies, significant remodeling of the temporomandibular joint after distraction osteogenesis does not appear to occur.¹⁸ Furthermore, the gradual joint loading does not appear to exacerbate preexisting disease.¹¹

Inferior Alveolar Nerve

Makarov and colleagues demonstrated that distraction osteogenesis produces minimal effect on the function of the inferior alveolar nerve in a canine model.¹⁹ Others report a range of neurosensory deficits.²⁰ In the rat model, the safest and fastest rate of distraction was determined to be 1 mm/d.²¹ Jaw-jerk reflexes remain intact. Most recently, Whitesides and Meyer showed that even large mandibular advancements (> 10 mm) can be accomplished without significantly damaging the inferior alveolar nerve.²²

Soft Tissue

A significant advantage of the distraction technique is concomitant expansion of the soft tissue envelope.¹⁷ Muscle and periosteum have been shown experimentally to undergo elongation and hyperplasia.²³ Although it appears that the change in muscle tissue is dependent on the degree of lengthening, it can be said that there are adaptations in the sarcomere length, an increased number of myocytes,^{11–24} and an increase in the volume of the attached muscles.²⁵

Teeth

Orthodontic tooth movement can be performed in distracted bone.^{26,27}

Indication for Maxillomandibular Advancement with Distraction Osteogenesis

Evaluation

The primary evaluation method is the functional clinical assessment in a multidisciplinary setting. Vital signs, including height and weight to allow calculation of the BMI, are obtained. Examination includes documentation of facial and other physical parameters, such as mandibular excursions, maximum interincisal opening, the state of the dentition, the presence of an occlusal cant, and classification of occlusion. An estimation of tongue volume and classification of soft palate and temporomandibular joint pathology should be noted.^{12–28} Nasopharyngoscopy is performed. A review of a recent (within 6 months to 1 year) polysomnogram is imperative.

Radiographic Assessment

Cephalometric analysis determines skeletal and dental relationships and abnormalities. The panoramic radiograph is used to provide a view of the position of teeth and to assess for impacted teeth or bony pathology. The panoramic radiograph is also valuable in the evaluation of the size and shape of the condyle, body, and mandibular ramus.

Rationale for Selection of the Treatment Modality

Patients are referred to the alternatives to continuous positive airway pressure (CPAP) if they are intolerant of CPAP, require information about nonsurgical treatments for the disease, or are considering a surgical procedure owing to impaired quality of life owing to untreated OSA. If the patient has mild to moderate OSA, the following options are discussed if applicable: lifestyle changes, dental appliances, weight loss, and nocturnal positional therapy. Owing to the deficiencies in current data supporting laser-assisted uvuloplasty, UPPP, GA or GAHS,

somnoplasty, sclerotherapy, tongue suspension, and glossoplasty, these procedures are seldom endorsed.

MMA is recommended for patients with moderate to severe OSA who have an RDI of < 70 and a BMI of < 32 kg/m². Interested patients with a BMI of 40 kg/m² may obtain a referral for consultation with a bariatric surgeon. If the RDI is > 70 or the BMI is > 32 kg/m², MMADO is advocated.

Technique of Distraction Osteogenesis

Distraction Device

A variety of hardware (KLS Martin L.P., Jacksonville, FL) has been investigated for MMADO. One prototype consists of two titanium miniplates connected by two screws and an encasement (Figures 38-1 to 38-4). The plates are completely



FIGURE 38-1 Distraction device closed.

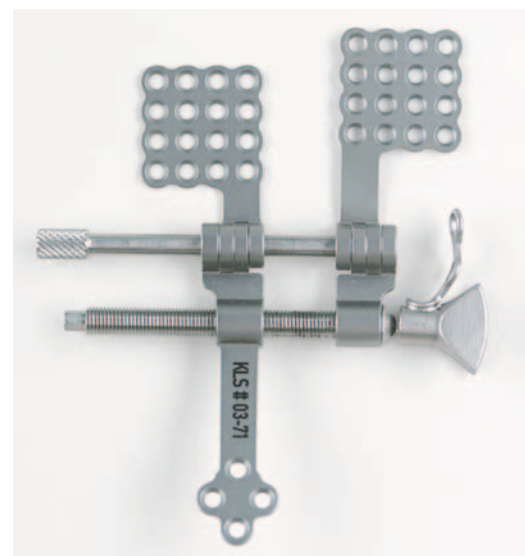


FIGURE 38-2 Distraction device open.

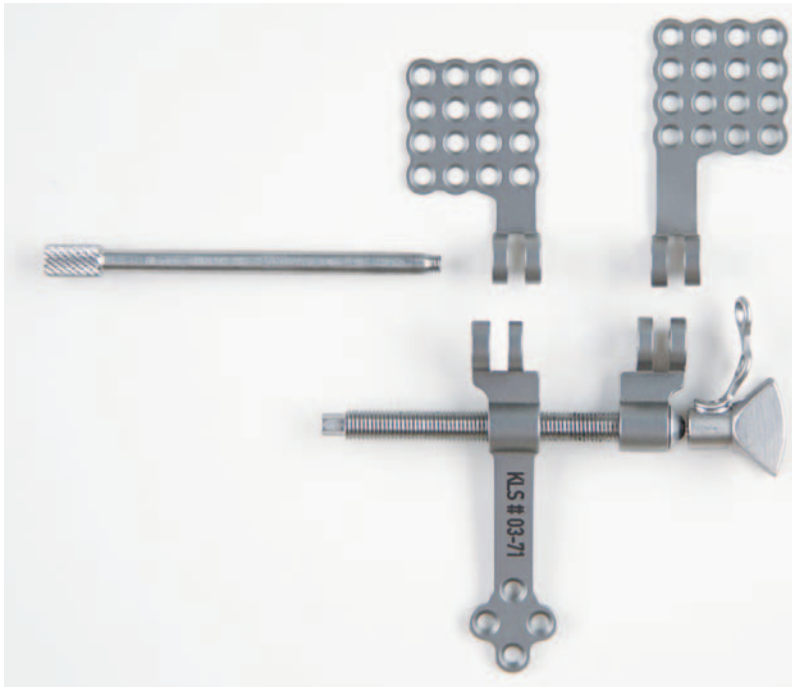


FIGURE 38-3 Components of the distraction device.

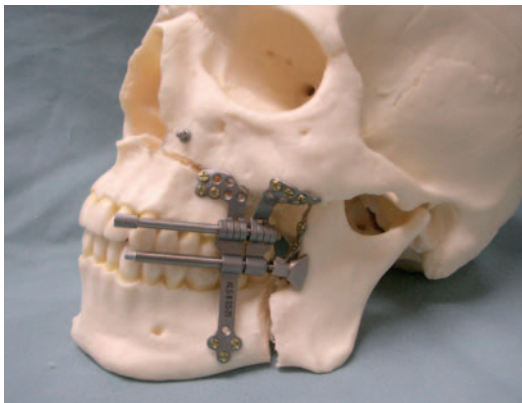


FIGURE 38-4 Distraction device applied and fixed in a bimaxillary fashion. As stated in the text, in all of our cases, the application was performed only in the mandible while the maxilla was fixed to the mandible by maxillomandibular fixation.

implanted subperiosteally and secured with monocortical screws. The projecting screw head remains intraorally. Each half-turn of the screw produces approximately 0.25 mm of distraction. The maximum distraction obtainable with the device was 25 mm. The device has been designed for versatile applications and for bimaxillary or monomaxillary placement. In all clinical cases, we have used an intraoral mandibular distraction application while the maxilla was indirectly advanced via ligation to the mandibular arch by way of maxillomandibular fixation.

Surgery

All surgical procedures were supervised by a single oral and maxillofacial surgery attending

physician. Oral intubation with conversion to tracheostomy is performed, and maxillary and mandibular circumdental arch bars are placed. A standard Le Fort 1 maxillary osteotomy is accomplished, and the maxilla is mobilized with full downfracture. The posterior mandible is approached via a buccal incision similar to that of a sagittal split osteotomy. A full-thickness mucoperiosteal flap is elevated, and a transverse posterior body osteotomy is initiated with a reciprocating saw under saline irrigation and completed with an osteotome. Care is taken to avoid the mandibular nerve by using two fiber-handle osteotomes at the same time, a narrow one at the inferior border of the mandible and the other at the level of the retromolar trigone. The occlusion is maintained via maxillomandibular arch bar fixation. The buccal sulcus distraction device is placed transorally and subperiosteally at the time of surgery, parallel to the inferior border of the mandible. The number of monocortical screws may vary, but a minimum of three screws are needed on either side of the osteotomy. Device trajectory is planned for a purely horizontal orientation, but owing to the socket-ball joint in the posterior aspect of the device, the direction can be corrected with elastic traction from intermaxillary fixation screws placed at the level of the piriform rim. The device is activated to ensure separation of the bony segments and is then neutralized into the closed position. Patients selected for this procedure are obese and/or have severe OSA and thus should be admitted to the intensive care unit because of the potential for airway control in the immediate postoperative period.

Postoperative oral antibiotics are administered for 1 week.

Distraction Protocol

Lateral cephalometric and Panorex radiographs are obtained as soon as possible in the postoperative period to evaluate for hardware position, prior to patient release from the hospital. Families must be provided with extensive counseling regarding wound care, oral hygiene, diet, activity, and tracheostomy care. The diet is completely liquid for the period of distraction and stabilization.²⁸

After a latency period of 7 days, distraction is initiated at a rate of 1 mm per day, completed in 0.5 mm cycles twice daily. Progress is monitored by serial lateral cephalometric radiographs at 1- to 2-week intervals. At the same interval, patients undergo clinical examination to evaluate stability and assess for infection, occlusal changes, or hardware malfunction. Once the desired advancement of the maxillomandibular complex is achieved, the tracheostomy tube is "capped" and a polysomnogram is obtained. If evidence of residual sleep apnea is demonstrated, jaw advancement is further titrated, guided by repeat polysomnography in 1 week.¹¹ Once the polysomnogram demonstrates cure of the OSA, the devices are left in place in a neutral position for stable rigid fixation for a minimum period of 8 weeks. During distraction and consolidation, the use of maxillomandibular elastic traction is required to achieve the optimal skeletal and occlusal result.¹⁶ Distraction device removal is accomplished after the consolidation phase, under general anesthesia. Maxillomandibular arch bars are retained for control of the occlusion.

Results

Between January 2001 and July 2004, nine male patients whose ages ranged from 29 to 51 years completed the distraction and consolidation phase (Figures 38-5 to 38-12). Two further patients are excluded from the data: a 23-year-old male patient did not tolerate the distraction device, and a 46-year-old male patient has incomplete records and refused to comply with requests for postoperative polysomnography. No patient had a history of cleft, hypothyroidism, temporomandibular joint ankylosis, tumor, or trauma to the upper airway. No patient had previous palate or jaw surgery for OSA. All eight patients underwent perioperative tracheostomy and subsequently decannulated.

Two patients were found to have residual sleep apnea on the first postdistraction polysomnogram. One additional week of distraction brought satisfactory polysomnographic results. Preoperative and postoperative demographic data are located in Table 38-3.



FIGURE 38-5 Preoperative frontal view.



FIGURE 38-6 Postoperative frontal view.



FIGURE 38-7 Preoperative lateral view.



FIGURE 38-8 Postoperative lateral view.

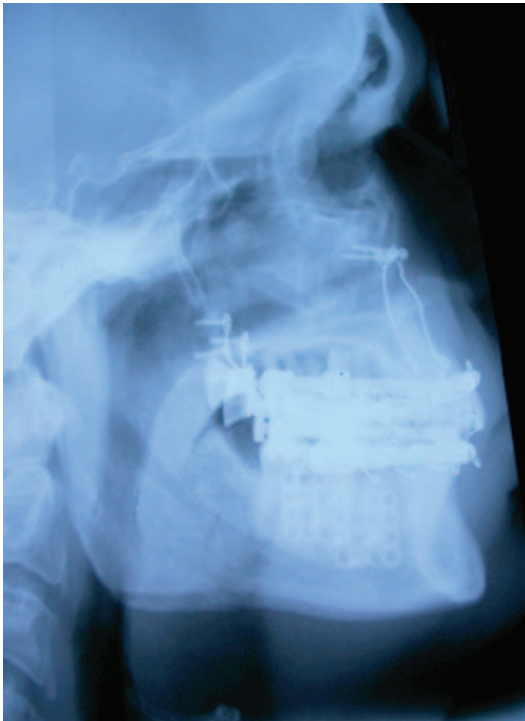


FIGURE 38-9 Predistraction Panorex radiograph.



FIGURE 38-10 Postdistraction Panorex radiograph.

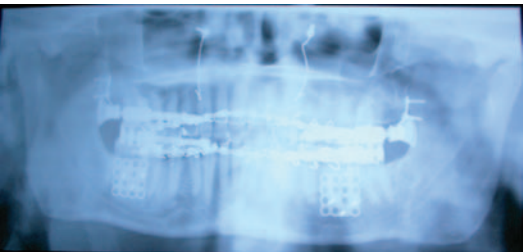


FIGURE 38-11 Predistraction cephalometric radiograph.

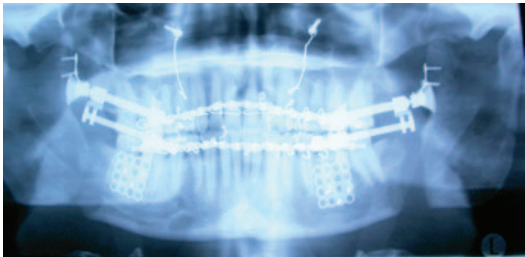


FIGURE 38-12 Postdistraction cephalometric radiograph.

Table 38-3 Results of Maxillomandibular Advancement via Distraction Osteogenesis
N = 9 (M = 9, F = 0)
Excluded two patients
Average age = 45 yr
BMI = 34.33; range 25–45.5
Postoperative PSG = 3 mo
Success = 100%
BMI = body mass index; PSG = polysomnogram.

Discussion

Sleep-disordered breathing with predominantly central apneas developed in one patient when the polysomnogram was conducted with the tracheostomy left uncapped at the immediate postdistraction polysomnogram. In a separate postoperative study, and tracheostomy was capped and a mixed central and obstructive pattern of disease persisted. Some patients had elimination or near-cure of the OSA yet struggled with persistent low desaturations during the polysomnogram. All of these cases are likely caused by obesity-hypoventilation syndrome, as described by Kim and colleagues.²⁹ Eight of nine patients had minimal remaining sleep pathology. Disease that did remain was converted from obstructive events to a predominance of hypopneas. The long-term significance of hypopneas remains unclear.

After distraction, a period of consolidation is necessary to allow for calcification, maturation of bone.³⁰ Histologically, investigators have shown that the new bone does not reach maturity for at least 2 months postdistraction.³⁰ Others project that at least 3 months is indicated if the jaw was significantly lengthened.¹¹ Clinically, this series of patients were distracted anywhere from 16 to 25 mm. The preoperative and postoperative BMI remained stable. Postoperative radiographs demonstrated evidence of bony relapse and simply did not correlate with the advancement that was observed clinically on the distraction apparatus. One patient likely suffered relapse, which occurred because of a deficiency in the length of the consolidation period. Nonetheless, patients enjoyed the success of MMADO even with radiographic evidence of relapse. Relapse is reported to be uncommon in the technique of distraction osteogenesis.¹¹ In our accumulated experience, we can consistently identify some degree of relapse in large bimaxillary advancements. We are in the process of quantifying the amount and determining the direction of the relapse.

We are at a loss to explain why the procedure is successful in eliminating much of the sleep pathology in the setting of relapse. It is possible that the relapse contributes to the minimal change in facial esthetics, thus minimizing complaints regarding facial changes.

Review of the existing literature indicates that very little work has been completed in investigating MMADO as a treatment for OSA. The two significant reports of OSA treated with distraction osteogenesis focused only on mandibular osteodistraction, with a single case undergoing bimaxillary distraction.^{31,32} In the most recent of the two reports, the patients were younger and almost half of the patients had

unilateral or bilateral temporomandibular joint ankylosis preoperatively.³¹ Other published literature includes limited case reports, again mostly single jaw distraction efforts.^{33–36}

The most significant advantage to the use of distraction osteogenesis is the possibility of obtaining skeletal movements that simply cannot be achieved with the more traditional osteotomy procedures.³⁷ MMADO eliminates bone grafting and thus avoids donor-site morbidity. MMADO can be used after bone graft or sagittal split osteotomy failure.³⁸ Distractor placement requires less stripping of the soft tissues from the mandible, which otherwise might decrease vascularity.¹¹ MMADO is available to patients who have preexisting temporomandibular joint disease or internal derangement. Intraoral distractor placement has overcome obstacles to patient acceptance factors such as esthetics and facial nerve injury. Temporary and permanent neurosensory changes occur with both MMADO and conventional MMA osteotomies for lengthening the jaws.¹¹

Several disadvantages exist. This is an evolving application of an existing technology, and a learning curve exists. Protection of the airway requires perioperative tracheostomy and the risks inherent to this procedure. Significant lengthening of the maxillomandibular complex results in malocclusion, likely owing to the postoperative relapse.³² The incidence of malocclusion does not seem significantly different from that reported in major pediatric craniofacial osteodistraction applications. However, the adult patient population is less willing to undergo a course of postoperative orthodontic treatment and attempted function with a malocclusion could induce temporomandibular joint dysfunction and damage teeth or restorations. Patients being considered for this procedure should be counseled preoperatively about the risks to speech, certainly if a previous palatal surgery has been performed or a preoperative defect, such as a cleft or velopharyngeal insufficiency, exists.³⁹ Finally, treatment time is extensive, which has implications for patients and practitioners. Patients will quickly lose their enthusiasm for procedures that have protracted treatment time. They may become unhappy, which would most certainly deteriorate should the surgical outcome be anything less than successful.

This chapter summarizes the use of distraction osteogenesis for the treatment of selected cases of severe OSA. Patients with active disease communicate the significant negative impact in the quality of life and recognize their potential increase in the risk of morbidity associated with OSA. Treatment of the aforementioned patient population with traditional surgical techniques is extremely difficult, if not impossible, owing to

an inability to achieve the required jaw advancement. The exact protocol, parameters, and indications for MMADO may require modification in response to ongoing data collection regarding traditional OSA surgical techniques. In addition, a limited number of cases with limited follow-up have been completed. It is increasingly clear that this treatment modality should be a multidisciplinary effort involving speech pathology, orthodontics, restorative dentistry, and oral and maxillofacial surgery in addition to the traditional sleep apnea team. OSA has pathologic contributions from anatomy and neuromuscular control; thus, the exact role of distraction osteogenesis in the surgical management of OSA is yet to be clarified.

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Treatment of Obstructive Sleep Apnea by Immediate Surgical Lengthening of the Maxilla and the Mandible

Reginald H. Goodday

Obstructive sleep apnea syndrome (OSAS) is a common disorder that predisposes a patient to significant social discord, cardiovascular disease, decreased pulmonary function, and accidental injury or death. The prevalence of sleep-disordered breathing, defined as an apnea-hypopnea index (AHI) of at least 5, is estimated to be 24% of adult men and 9% of adult women. The incidence of OSAS, which is defined as an AHI ≥ 5 , and self-reported excessive daytime sleepiness is 4% and 2% of middle-aged (30–60 years) men and women, respectively, whereas estimates for elderly men range from 28 to 67% and from 20 to 54% for elderly women.¹

Clinical Manifestations

General signs related to OSAS include obesity, increased neck circumference, and hypertension. It is important to note, however, that approximately 30% of people with OSAS are not obese,² and this diagnosis should still be considered in nonobese patients who present with symptoms of this sleep disorder (Figure 39-1).

Excessive daytime somnolence is a key feature, and patients may report that they frequently fall asleep during the day while driving, working, reading, and watching television (Figure 39-2). Performing activities related to transportation or the use of machinery and heavy equipment can put both the patient and others at significant risk of injury. Chronic daytime sleepiness also leads to poor work performance and decreased productivity. Snoring, ranging in severity from mild to extremely loud, is invariably present. The partners of people with OSAS may witness gasping, choking, or periods of apnea with repeated arousals through the night. Other complaints include a feeling of not being rested despite a full night of sleep, dry mouth, morning

headaches, absence of dreams, fatigue, decreased libido, and symptoms of depression.

Advanced cases of OSAS have respiratory consequences secondary to pulmonary hypertension, cor pulmonale, chronic carbon dioxide retention, and polycythemia. The cardiovascular consequences of OSAS may include systemic hypertension, cardiac arrhythmias, myocardial infarction, and cerebrovascular accidents, all of which lead to a higher mortality rate than in the general population.

Clearly, OSAS can be a debilitating and potentially life-threatening condition. Thus, both proper diagnosis and appropriate treatment are important.

Pathophysiology of OSAS

To recommend the best treatment option for the patient, it is necessary for the clinician to understand the underlying pathology. Obstructive sleep apnea (OSA) can be caused by an anatomic abnormality that narrows or obstructs the airway. The upper airway has been categorized into three anatomic regions: (1) the nasopharynx (the nasal turbinates to the hard palate); (2) the oropharynx, which is subdivided into the retropalatal (the caudal margin of the hard palate to the caudal margin of the soft palate) and retroglossal (the caudal margin of the soft palate to the base of the epiglottis) regions; and (3) the hypopharynx (the base of the tongue to the cervical



FIGURE 39-1 Patients with obstructive sleep apnea syndrome. A, Patient with increased neck circumference. B, Nonobese patient.



FIGURE 39-2 Patient with severe obstructive sleep apnea (apnea-hypopnea index 121). This patient could barely stay awake while being photographed. A, Profile view. B, Frontal view.

esophagus).³ Upper airway closure in the majority of patients with OSA occurs in the retropalatal and retroglossal regions (Figure 39-3). Forces promoting collapse of the pharynx include the negative intraluminal pressure created on inspiration and extraluminal pressure created by parapharyngeal soft tissues. Studies to localize the site of functional obstruction in the upper

airway have shown that there is rarely a single anatomic site of occlusion but, more commonly, multiple sites of upper airway obstruction during episodes of hypopnea and apnea.⁴ For this reason, surgical treatment that addresses only one site is predisposed to a low success rate when treating a multisite problem.

Cephalometric studies have demonstrated that compared with normal controls, OSAS patients have a repositioned mandible and/or maxilla, a short cranial base, an increased mandibular plane angle, increased facial height, narrow posterior airway spaces, an enlarged tongue and soft palate, and inferiorly positioned hyoid bones.⁵⁻¹⁰ In the majority of computed tomography and magnetic resonance imaging studies, the upper airway of apneic patients is narrower than that of normal controls. Authors have demonstrated the craniofacial risk factors for OSAS to be more common in the nonobese versus the obese OSAS patient.^{6,11}

Treatment Options

To assist the patient in making an informed decision regarding treatment choices, the oral and maxillofacial surgeon must be familiar with the risks and benefits of common options.

OSAS can be managed nonsurgically or surgically. The treatment should target the potential contributing factors identified by the history, the physical examination, and upper airway

imaging. The severity of the patient's condition must also be considered in developing a treatment plan.

Nonsurgical Management

Because obesity is a risk factor for OSAS, a reduction in body weight can reduce sleep apnea. In the Wisconsin Sleep Cohort study, a 10% weight gain predicted a 32% increase in AHI, whereas a 10% weight loss predicted a 26% decrease in AHI.¹² However, it should be noted that the recurrence of OSAS has been reported after surgically induced weight loss even though the weight was not regained. Patients may have difficulty losing weight, particularly in more severe cases, because excessive daytime somnolence and fatigue may discourage the patient from exercising. The severity of the OSAS may have to be reduced through some other form of treatment before an exercise program can be started.

The most successful nonsurgical treatment is continuous positive airway pressure (CPAP). Positive pressure is continuously delivered through a sealed mask that the patient wears while asleep. This positive pressure pneumatically splints the pharyngeal airway open by preventing the soft palate and tongue from occluding it. Unfortunately, because of physical discomfort associated with wearing the unit, drying of the nasal and oral mucous membranes, dislodgment during sleep, noise, and the social consequences of using the unit, the long-term compliance of CPAP use on a nightly basis can be as low as 25%.¹³

Oral appliances can also be used in the treatment of OSAS. A review of 20 studies, involving 304 patients, revealed that oral appliances were effective in 51% of cases, as defined by achievement of a respiratory disturbance index of less than 10.¹⁴ In two studies that compared oral appliances for mandibular advancement with CPAP, the oral appliances were effective in mild to moderate cases but were less effective than nasal CPAP in more severe cases. In both of these studies, the patients strongly preferred the oral appliance over nasal CPAP for reasons of comfort. The most significant negative long-term effects of oral appliances are movement of teeth and temporomandibular joint problems. The condyle is positioned and held in an abnormal spatial relationship to the articular eminence, and in some patients, this gives rise to pain and significant bony changes (Figure 39-4). Of further concern is the fact that a dental appliance will eliminate or decrease snoring in certain patients; however, their sleep apnea persists, and the patient is not aware of the need to seek further treatment. In the short term, a splint could be used for diagnostic purposes. Figure 39-5 demonstrates radiographic changes in the pharyngeal airway following mandibular advancement using a splint.



FIGURE 39-3 Anatomic regions of the pharyngeal airway. Upper airway closure in the majority of patients with obstructive sleep apnea occurs in the retropalatal and retroglossal regions.

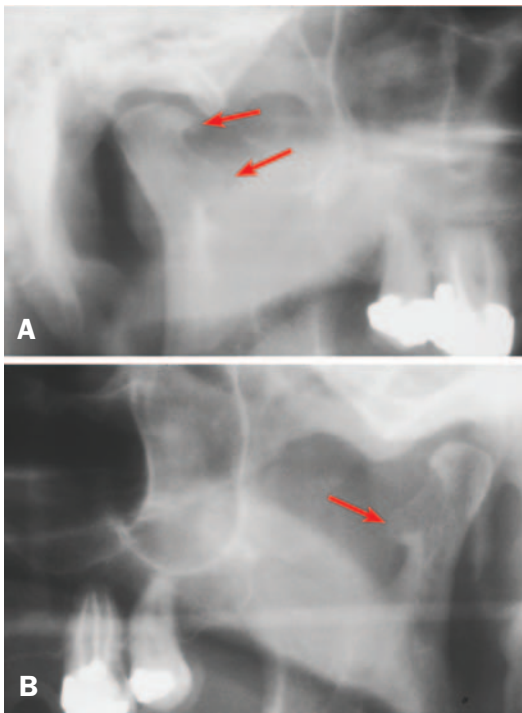


FIGURE 39-4 Bony changes in a patient with obstructive sleep apnea syndrome as a result of long-term use of an oral appliance. *A*, Lipping of the right condylar head and bone growth in the area of attachment of the right lateral pterygoid muscle. *B*, Bone growth in the area of attachment of the left lateral pterygoid muscle.

These changes can be achieved or even surpassed with surgical advancement.

Surgical Management

Tracheostomy was the first successful surgical treatment for OSAS and has virtually a 100% success rate because it bypasses the obstruction of the upper airway completely. Complications associated with tracheostomy include hemorrhage, recurrent infections, airway granulations, and tracheal or stomal stenosis. The medical and obvious social problems associated with tracheostomy stimulated the research for alternatives.

Fujita and colleagues first described the use of uvulopalatopharyngoplasty (UPPP) for the treatment of OSAS in 1981.¹⁵ This procedure involves shortening the soft palate, amputating the uvula, and removing redundant lateral and posterior pharyngeal wall mucosa from the oral pharynx. Despite the popularity of this procedure, reviews have reported improvement in less than 50% of patients and complete control of OSAS in 25% or less.¹⁶ This low success rate is probably due to the fact that OSAS patients obstruct at multiple sites and this surgery addresses only one level of the area of obstruction. In addition, the soft tissue changes that take place in the retropalatal region appear to be unpredictable and in many cases may result in a detrimental change in the pharyngeal anatomy (Figure 39-6).

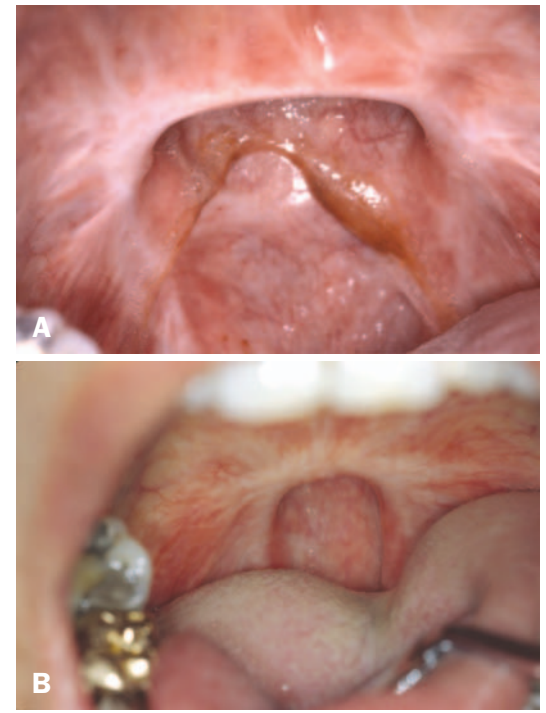


FIGURE 39-6 *A* and *B*, Nasopharyngeal stenosis in patients following uvulopalatopharyngoplasty.

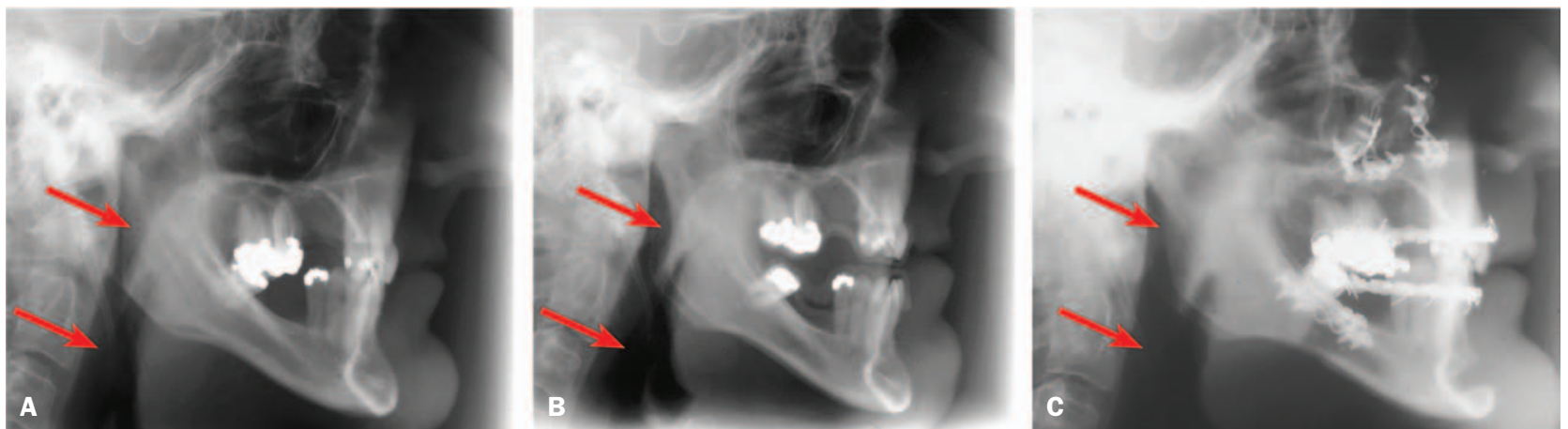


FIGURE 39-5 Retropalatal and retroglottal pharyngeal airways (arrows). *A*, Before treatment. *B*, Postinsertion of a dental appliance to advance the mandible. Note the significant improvement in the retroglottal region. *C*, Post-maxillomandibular advancement surgery, which produced a greater increase in the retroglottal and retropalatal pharyngeal airways.

Clinical examination of patients who have previously undergone UPPP reveals a soft palate that appears shorter and has a firm scar band on the inferior surface. Lateral cephalometric radiographs of these patients reveal that although the soft palate is much shorter, it is also much thicker, which can result in a narrow retropalatal pharyngeal airway (Figure 39-7). Figure 39-8

demonstrates the radiographic soft tissue changes in the drape of the soft palate before and after a UPPP surgical procedure. In this case, the retropalatal airway has not improved and the retroglossal airway has, in fact, decreased. These changes can explain why the severity of OSAS actually increases in some patients after this procedure.

Because UPPP is often performed as the first line of surgical treatment for OSA, despite its high failure rate, the oral and maxillofacial surgeon needs to regularly perform orthognathic surgery on these patients to correct the underlying skeletal deformity contributing to the patient's OSA (Figure 39-9). In theory, the altered pharyngeal anatomy may compromise this surgery by limiting the advancement, and the patient could also be at risk of velopharyngeal insufficiency (Figure 39-10). Because of this concern and to provide information to these patients regarding

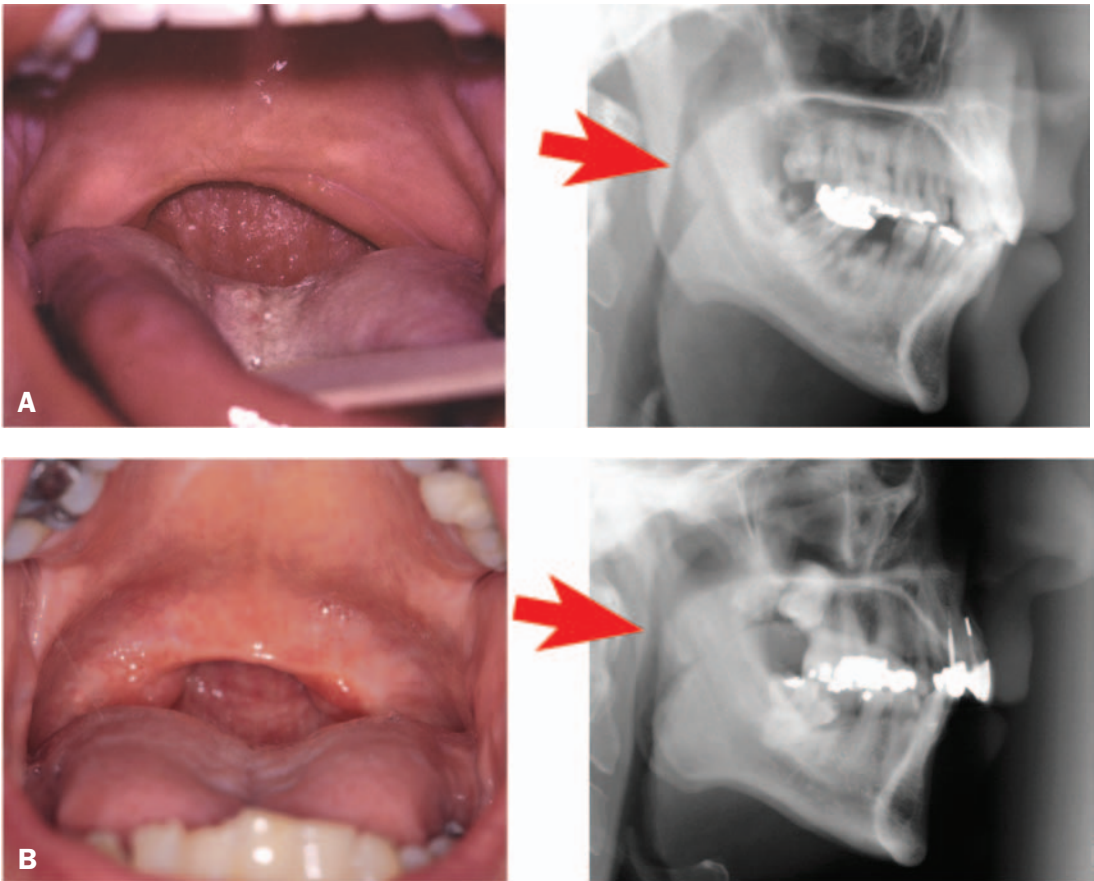


FIGURE 39-7 A and B, Clinical view of the soft palate with corresponding radiographs in two patients with obstructive sleep apnea syndrome who have undergone uvulopalatopharyngoplasty that failed. The soft palate is shorter and thicker than normal, and the retropalatal pharyngeal airway does not appear to have improved.

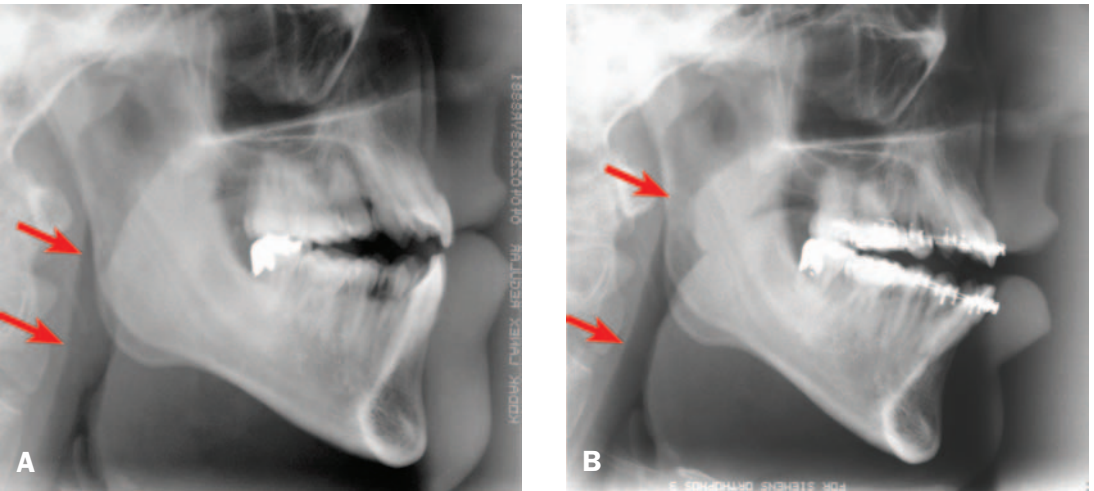


FIGURE 39-8 Changes in the pharyngeal airway following uvulopalatopharyngoplasty (UPPP). A, Before UPPP. B, After UPPP. Note that the retropalatal airway has not improved and the retroglossal airway has decreased. The normal palatal drape is now abnormal.



FIGURE 39-9 Patient with obstructive sleep apnea syndrome with an obvious dentofacial deformity who has undergone uvulopalatopharyngoplasty (UPPP), which failed. A, Profile view. B, Lateral cephalometric radiograph. Note the obtuse nasolabial angle (140°) and the retroclined maxillary incisor teeth, which are typical findings in a patient with retrognathia. Note the relatively narrow retropalatal and retroglossal airways post-UPPP.

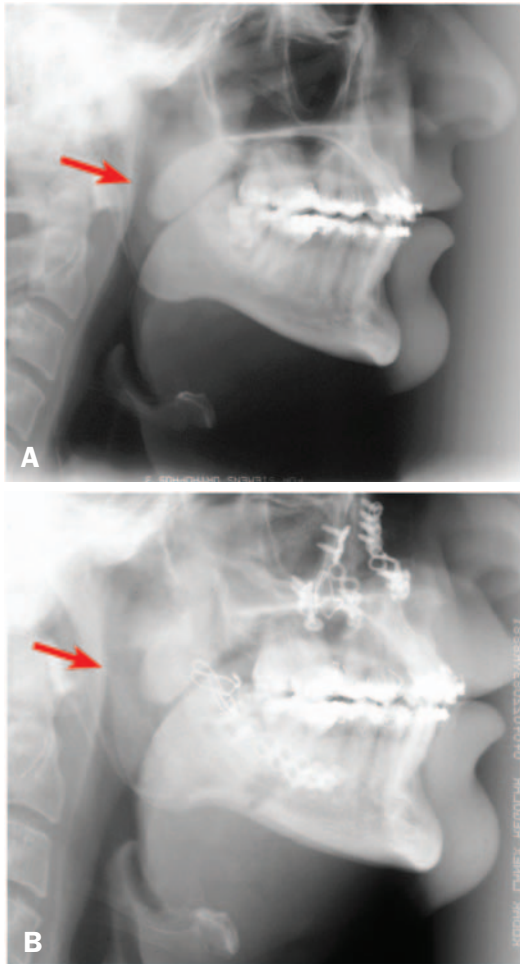


FIGURE 39-10 A and B, Pre- and postsurgery radiographs following maxillomandibular advancement in a patient who had previous uvulopalatopharyngoplasty, that failed. Although there is a significant increase in the retropalatal airway (arrows), nasal regurgitation or a change in speech quality did not occur.

the risks of maxillomandibular advancement (MMA) surgery, Robertson and Goodday reviewed 14 patients treated by MMA for OSAS who had undergone previous UPPP.¹⁷ MMA produced significant reductions in excessive daytime sleepiness, snoring, and witnessed apneas without long-term nasal regurgitation or a change in speech. In this study, twice as many subjects stated that the UPPP was a more painful procedure than MMA. When asked if they would undergo UPPP or MMA again, all subjects reported that they would undergo MMA again. Only one subject would undergo UPPP again; however, this patient indicated that he felt that the UPPP decreased the frequency of sore throats but had no effect on his OSAS.

The use of orthognathic surgery to treat OSAS began toward the end of the 1970s, when mandibular advancement was reported to have reversed the symptoms of OSAS. Since then,

this procedure has become widely accepted. Advancement of the mandible repositions the anterior belly of the digastric, mylohyoid, genioglossus, and geniohyoid muscles forward. This, in effect, pulls the tongue upward and away from the pharynx. Advancing the maxilla pulls the soft tissue of the palate forward and upward. This also pulls the palatoglossal muscles and increases tongue support. Both movements increase the available tongue space.

Hochban and colleagues reported a series of 38 consecutive patients with OSAS treated by 10 mm MMA.¹⁸ All patients preoperatively had subjective symptoms of daytime sleepiness and an AHI greater than 20. Thirty-seven of 38 patients had a postoperative AHI of less than 10.¹⁸ In 1999, Prinsell reported on 50 cases of MMA using success criteria that included a lowest oxygen saturation of > 80%, an AHI < 15, and an apnea index (AI) < 5, or a greater than 60% reduction in AHI and AI, with all patients having an AI < 10.¹⁹ All 50 patients were treatment successes.

Distraction osteogenesis (DO) was recently recommended for treatment of OSAS patients who have severe micrognathia and are not felt to be candidates for MMA owing to extremes of age, soft tissue scarring and fibrosis, and magnitude of the required movements. The stated advantages of this technique would include the elimination of a need for an autogenous bone graft, the possibility for larger bony advancements, and a stable result with minimal relapse.

Controversy exists regarding the need to perform a concomitant bone graft from a distant site in patients undergoing MMA. Many surgeons feel that this additional procedure is necessary to ensure stability and good bone healing at the maxillary osteotomy site. Gregoire reviewed 131 patients who underwent MMA to treat OSAS using bone grafted from local sites (eg, chin) to determine the incidence of fibrous union.²⁰ Only four patients (3%) required a second procedure to harvest bone from either the tibia or the iliac crest to treat fibrous union of the maxilla.

The disadvantages of DO include the need for approximately 4 months of active treatment time, which requires a very compliant patient and multiple clinic visits. The procedure is highly technique sensitive in achieving proper alignment of the distraction devices as inadequate vector control can result in a significant malocclusion. It is difficult to address a multisite anatomic problem (ie, maxillary and mandibular retrognathia), and it is not clear how the clinician determines the exact “magnitude of the required movement,” other than trial and error. It does appear that DO offers significant advantages in the management of severe craniomaxillofacial skeletal deformities, and further investigations are necessary to

determine the potential of this technique to treat OSA patients.

Diagnosis and Treatment Planning for MMA Surgery

The diagnosis of OSA is made after a thorough history and clinical examination, cephalometric radiography, and polysomnography in a sleep laboratory. The sleep study will confirm and quantify the severity of the OSAS. The clinical examination will allow the surgeon to identify soft tissue abnormalities such as webbing of the soft palate (Figure 39-11) or pharyngeal redundancy, which may respond to soft tissue surgery only. Indentations on the lateral border of a normal tongue would support advancing the maxilla and mandible to provide more volume to improve the retroglottal airway (Figure 39-12). The cephalometric radiograph is an important diagnostic aid that will demonstrate both bony and soft tissue abnormalities related to the soft palate, pharyngeal airway, and maxillomandibular complex. If radiographic and clinical examination of the soft tissues of the pharynx reveals a narrow airway in conjunction with retrognathia of the maxilla and mandible, then the patient should be deemed a candidate for an MMA procedure with or without advancement genioplasty (Figure 39-13).

The surgeon’s goal is to optimize the advancement of the deficient structure(s) while maintaining normal facial balance for each patient. It is beneficial to use a cephalometric analysis, which clearly demonstrates all of the maxillofacial abnormalities and provides a visual treatment objective.

Cephalometric Analysis

Delaire constructed an architectural and structural craniofacial cephalometric analysis that is based on mutual balance of the cranial and facial



FIGURE 39-11 Webbing of the soft palate, which can be addressed by soft tissue surgery only.

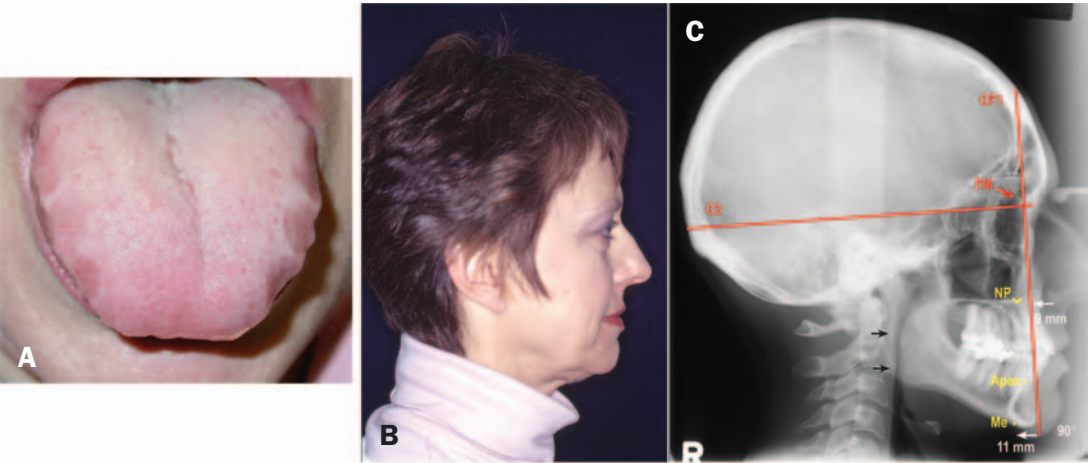


FIGURE 39-12 Indentations of the lateral border could suggest that the tongue is either too large or the oral cavity is too small. For this patient, cephalometric analysis supports the latter as the maxilla and the mandible can be advanced approximately 10 mm and still maintain normal facial balance. Note the narrow retropalatal and retroglossal airways. A, Tongue. B, Profile view. C, Lateral cephalometric radiograph with Delaire's lines of anterior facial balance.

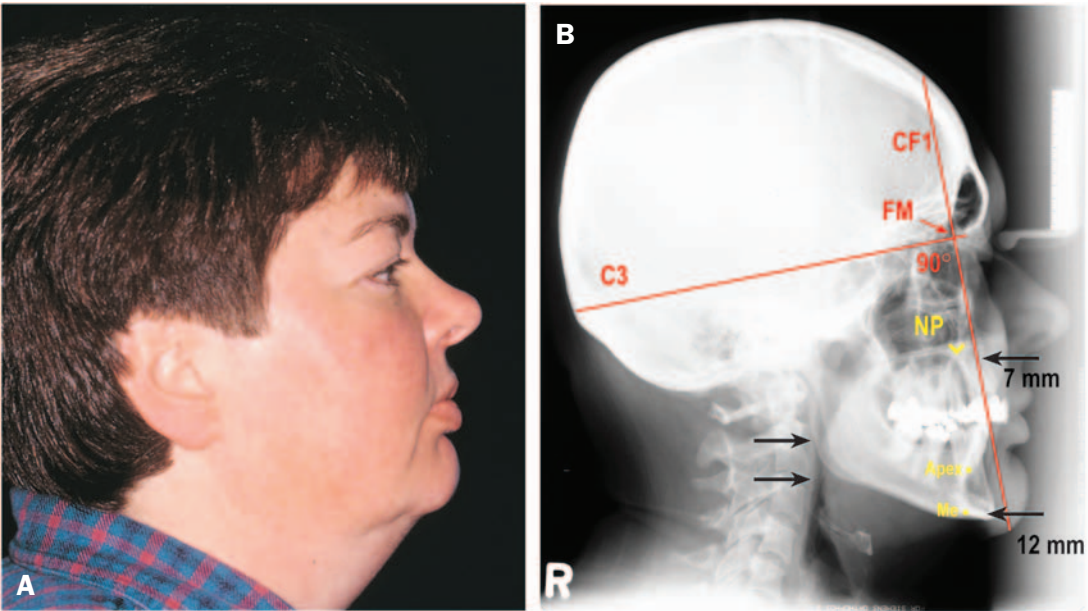


FIGURE 39-13 Patient with obstructive sleep apnea syndrome with a very narrow pharyngeal airway and retro-positioned maxilla and mandible who should be considered a candidate for maxillomandibular advancement. Delaire's analysis reveals that the mandible and the maxilla can be advanced 12 mm and 7 mm, respectively, and maintain normal facial balance. A, Profile view. B, Cephalometric radiograph with Delaire's lines of anterior craniofacial balance.

bony structures and allows the face to be studied in relation to the cranium and cranial spinal articulation (Figure 39-14).²¹ Statistical averages are avoided, and individual proportions influenced by the unique features of each skeleton are relied on. This analysis is very useful to the maxillofacial surgeon as it allows the clinician to determine the shape that the abnormal structure should have had, allows examination of the constitution of skeletal abnormalities graphically, and constructs

a visual treatment objective. The surgeon can predict the movements of the maxilla and mandible that can be achieved to enlarge the pharyngeal airway while staying within the range of normal facial balance for each individual. This ensures that the objective of treating the abnormal airway is not made at a cost of poor esthetics (Figure 39-15). In fact, the movement of abnormal structures into a more normal position tends to result in a favorable change from the point of

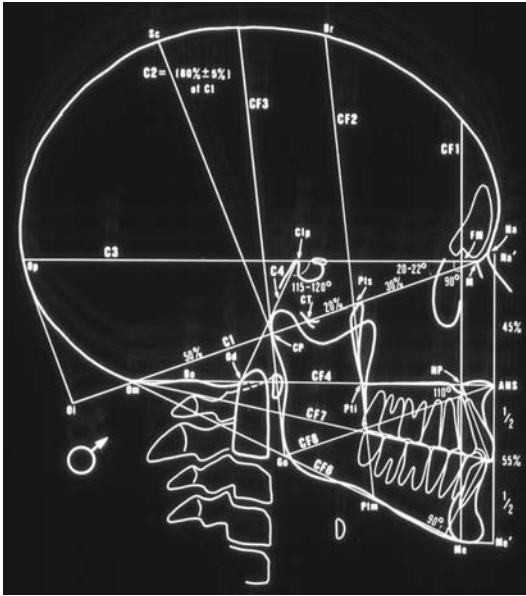


FIGURE 39-14 Delaire's architectural and structural craniofacial cephalometric analysis, which constructs a visual treatment objective and is useful to predict movements of the maxilla and the mandible that can be achieved to enlarge the pharyngeal airway while staying within the range of normal facial balance.

view of facial appearance (Figure 39-16). Robertson surveyed 20 patients and asked their opinion regarding their facial appearance following MMA surgery, and 85% felt that there was a change.²² Among these patients, 50% felt that the change was favorable, 5% felt that the change was unfavorable, and 30% were indifferent with respect to the changes (Table 39-1). Interestingly, a source of dissatisfaction for one patient who felt the change to be unfavorable was that some people she knew did not recognize her following MMA.

The lines of the Delaire analysis that analyze the anteroposterior balance of the face include C3 and CF1 (Figure 39-17). Line C3 is drawn from M point through the apex of the clinoid process and extends posteriorly until it intersects the external surface of the occipital bone. The M point is the junction of the nasal process of the maxilla and the maxillonasal and frontonasal sutures (see Figure 39-17). Line CF1 is the anterior line of craniofacial balance. It is traced passing through FM (frontomaxillary) point, which anatomically corresponds to the middle of the upper border of the ascending nasal process of the maxilla and its sutural articulation with the frontal bone (see Figure 39-17). This point lies on line C3 and resides at the center of the bony opacity created by the superior extremity of the ascending nasal process of the maxilla. It can be located directly below the ridge of reinforcement, which forms part of the base of the frontal sinus.

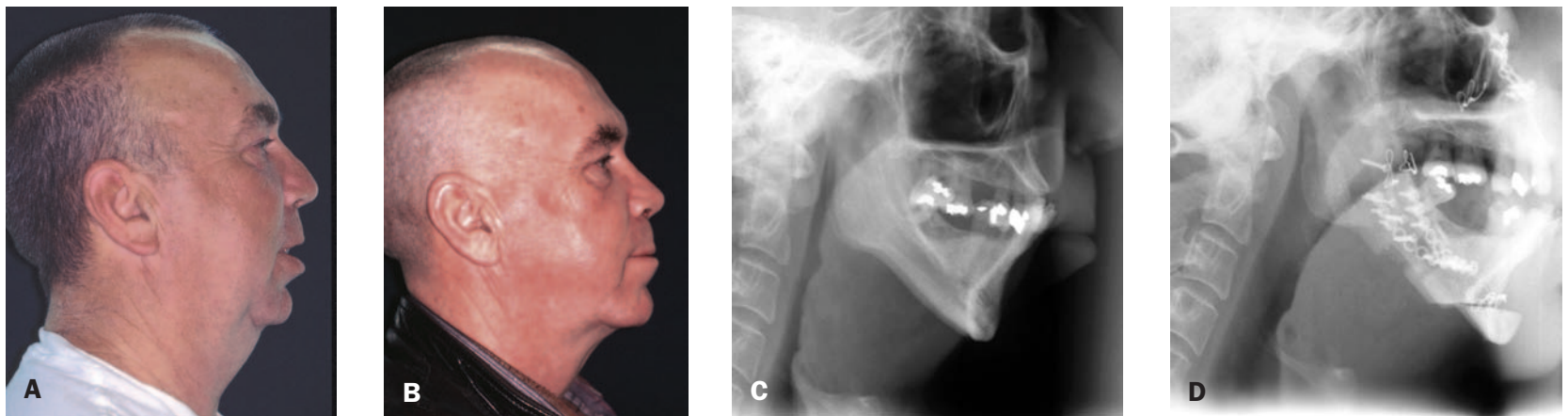


FIGURE 39-15 A to D, When the maxilla and the mandible are advanced to improve the pharyngeal airway, patients would like reassurance that facial features will not look abnormal following surgery. Clinical and radiographic changes in a patient with obstructive sleep apnea syndrome whose magnitude of maxillomandibular advancement (MMA) is determined by the Delaire analysis reveal that the patient has normal facial balance and significant improvement in the pharyngeal airway. A, Profile view before MMA. B, Profile view following MMA. C, Presurgery cephalometric radiograph. D, Postsurgery cephalometric radiograph revealing the extent of advancement and improvement in the pharyngeal airway.

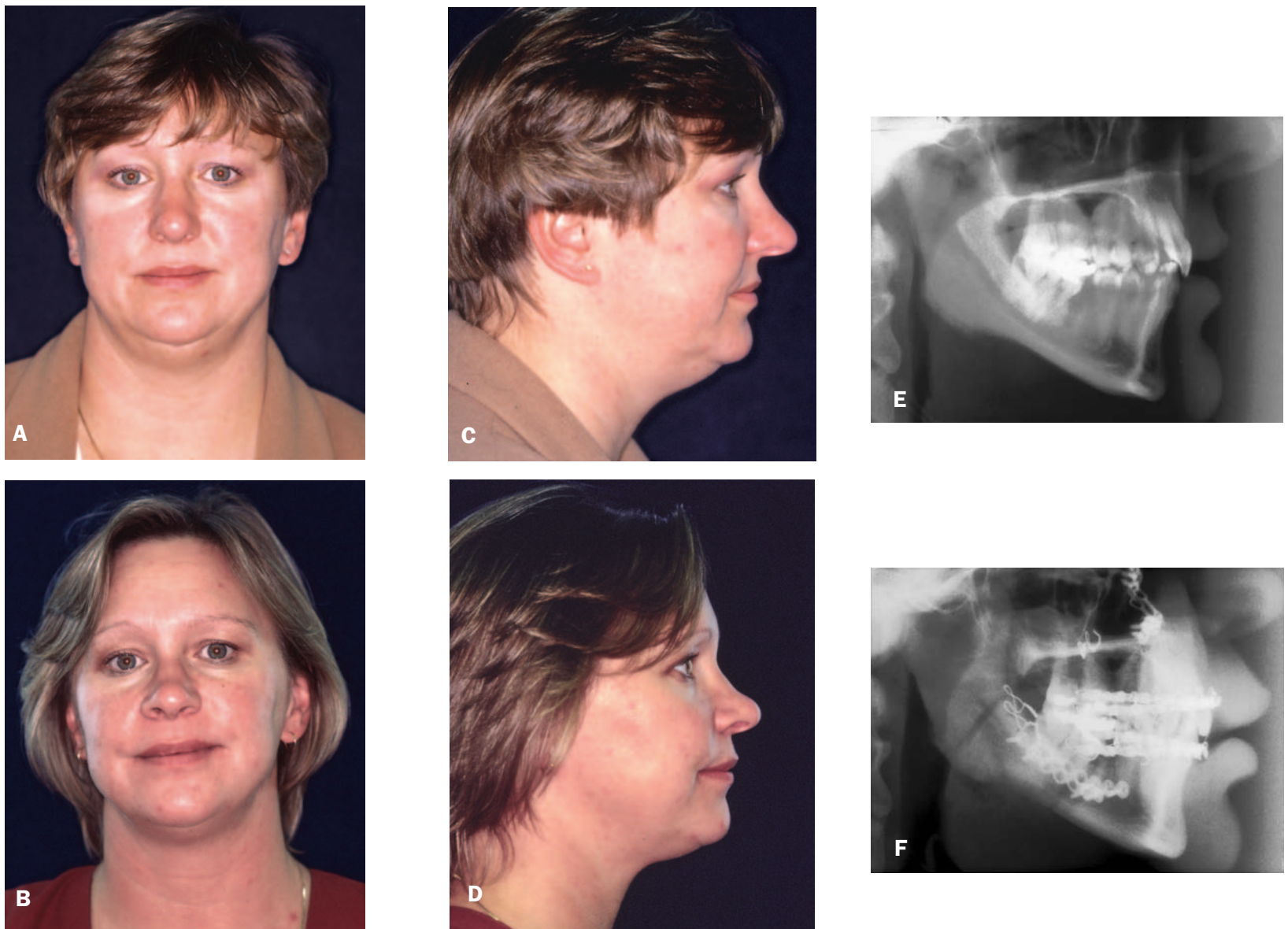


FIGURE 39-16 In many cases, movement of the maxilla and the mandible to a position of normal facial balance will result in actual improvement in facial esthetics. A, Frontal view presurgery. B, Frontal view postsurgery. C, Profile view presurgery. D, Profile view postsurgery. E, Lateral cephalometric radiograph before maxillomandibular advancement (MMA). F, Lateral cephalometric radiograph after MMA showing improvement in the pharyngeal airway.

Table 39-1 Change in Appearance Associated with Maxillomandibular Advancement	
Patient Response	Incidence, n (%)
No change in appearance	3/20 (15)
Change in appearance	17/20 (85)
Favorable	10/20 (50)
Unfavorable	1/20 (5)
Neutral	6/20 (30)

Line CF1 is extended upward to its intersection with the external frontal cortical bone and downward, passing below the bony menton. Angle C3/CF1 takes different values depending on the age and sex of the subject. For children, the angle is always 85°. After pubescent growth is complete, the normal values are 85 to 90° in females and 90 to 95° in males (see Figure 39-17).

Normally, line CF1 passes through the frontal sinus, FM point, the anterior border of the nasopalatine canal (NP point), the distal slope of the occlusal edge of the crown of the upper canine, the apex of the lower central incisor, and menton (Me point), which is the osseous point of contact between the posterior border of the

symphysis and the inferior border of the mandible (Figure 39-18A).

When NP point does not coincide with CF1, then a new CF1 can be constructed by drawing this line at an angle $\leq 95^\circ$ to C3 through FM point and extended beyond Me point. Thus, the following can be viewed objectively and eventually measured: the degree of maxillary retrognathia, the degree of mandibular retrognathia, and the degree of anteroposterior displacement between the maxilla and the mandible in relation to the “ideal” and to one another.

For male patients, the clinician can construct CF1 by drawing this line at an angle of 95° to C3 through FM point. The surgeon can then

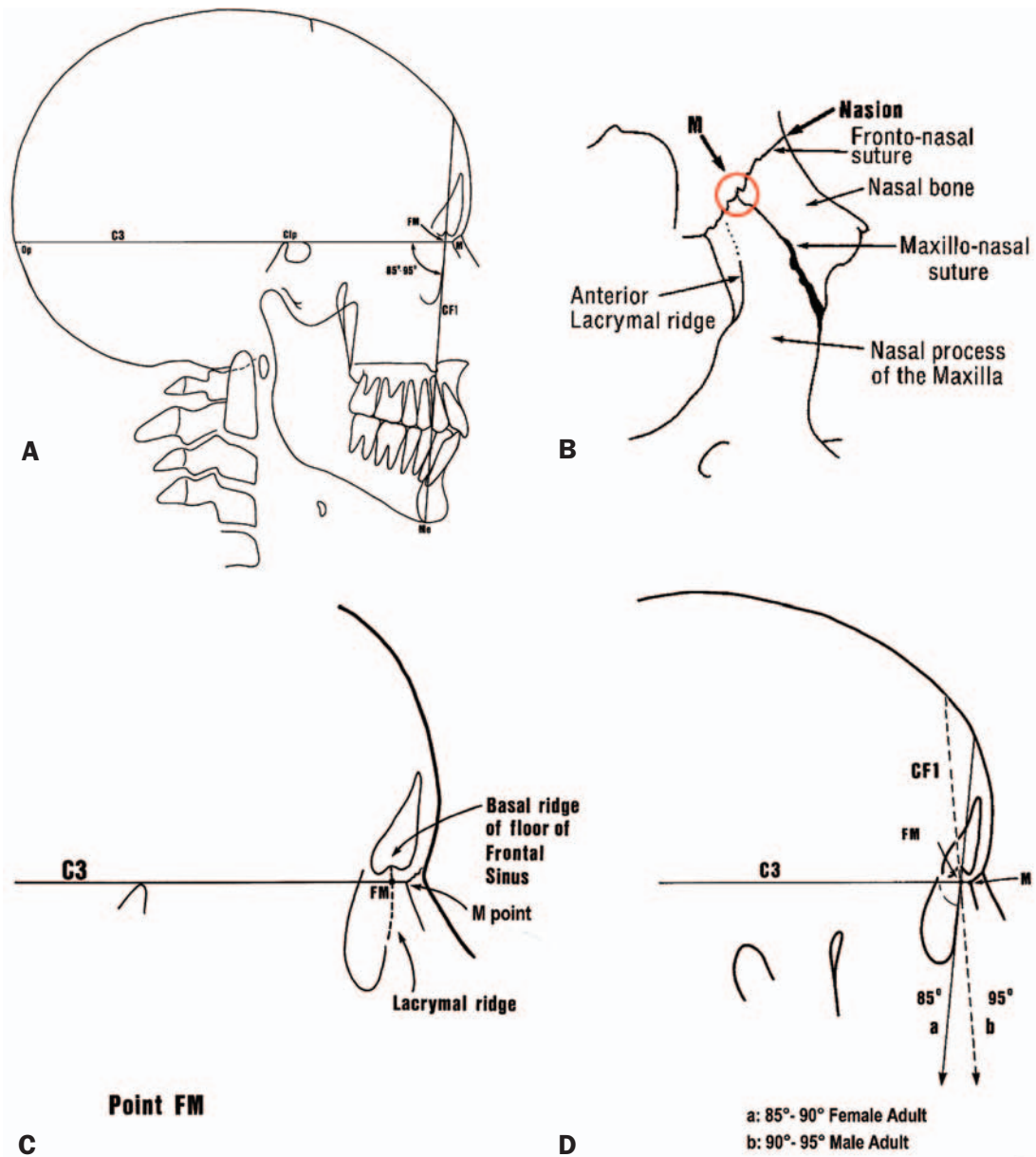


FIGURE 39-17 Lines of the Delaire analysis that analyze the anteroposterior balance of the face. A, Lines C3 and CF1. B, The M point is the junction of the nasal process of the maxilla and the maxillonasal and frontonasal sutures. C, The FM point anatomically corresponds to the middle of the upper border of the ascending nasal process of the maxilla and its sutural articulation with the frontal bone. This point lies on C3 and resides at the center of the bony opacity created by this ascending process, which spans the distance between the M point and the lacrimal ridge. D, Normal values for angle C3/CF1 are 85 to 90° in females and 90 to 95° in males.

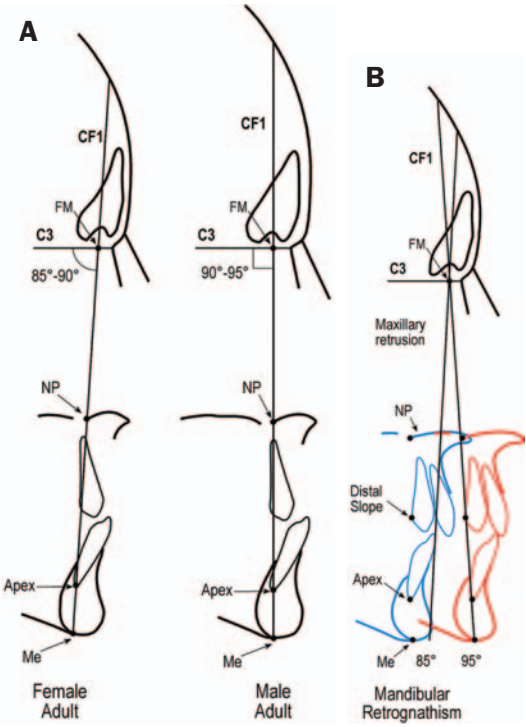


FIGURE 39-18 Line CF1. A, Normally, line CF1 passes through the frontal sinus, FM point, NP point (nasopalatine canal), distal slope of the occlusal edge of the crown of the upper canine, apex of the lower incisor, and Me point (menton), which is the osseous point of contact between the posterior border of the symphysis and the inferior border of the mandible. B, CF1 can be constructed by drawing this line at an angle $\leq 95^\circ$ to C3 through FM point. The surgeon can then measure the distance between the NP point and line CF1, knowing that if the maxilla is advanced so that the NP point lies on line CF1, the maxilla will be within the limits of normal facial balance. The surgeon should also measure the distance between the Me point and CF1, knowing that this is the amount of surgical advancement that can be performed while keeping the mandible within the limits of normal facial balance.

measure the distance between NP point and line CF1, knowing that if the maxilla is advanced so that NP point lies on line CF1, the maxilla will be within the limit of normal facial balance. The surgeon should also measure the distance between Me point and CF1, knowing that this is the amount of surgical advancement that can be performed while keeping the mandible within the limits of normal facial balance (Figure 39-18B). If menton lies behind CF1 when the line passes through the apex of the lower incisor tooth, then a genioplasty is required to advance the chin and associated muscles to both improve the pharyngeal airway and achieve facial balance (Figure 39-19).

Perioperative Treatment and Surgical Technique

Maxillary and mandibular advancements can be achieved using a Le Fort I maxillary osteotomy and a bilateral sagittal split osteotomy of the mandible, respectively (Figure 39-20). Unless

there is a Class II or III dentofacial deformity that is being corrected at the time of the surgery, synchronous advancement of the maxilla and mandible is performed to maintain presurgical

occlusion. A concomitant advancement genioplasty is performed in cases of anterior mandibular deficiency as determined by the preoperative cephalometric tracing.

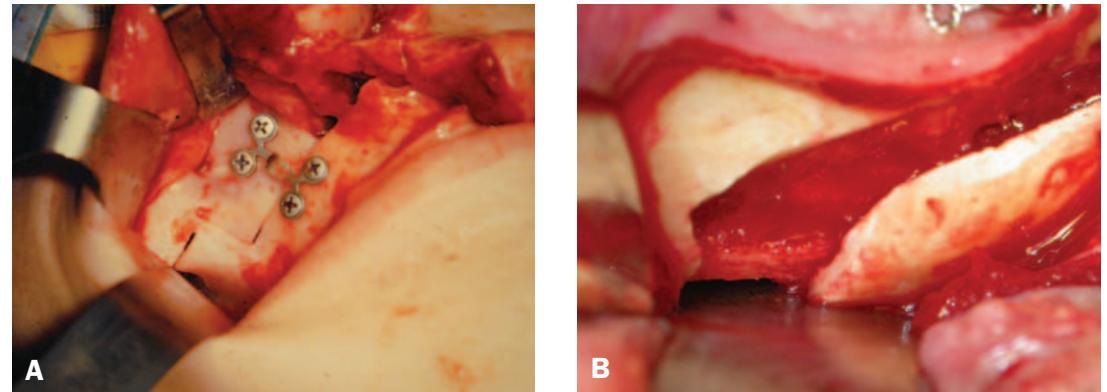


FIGURE 39-20 Maxillary and mandibular advancements. A, Maxillary advancement via Le Fort I osteotomy. B, Mandibular advancement via bilateral sagittal split osteotomy.

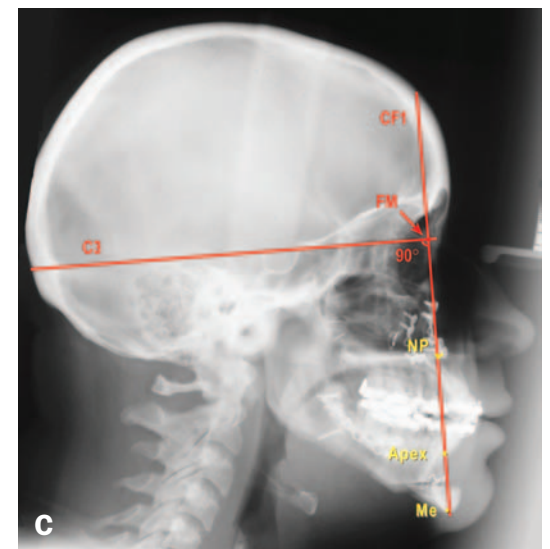
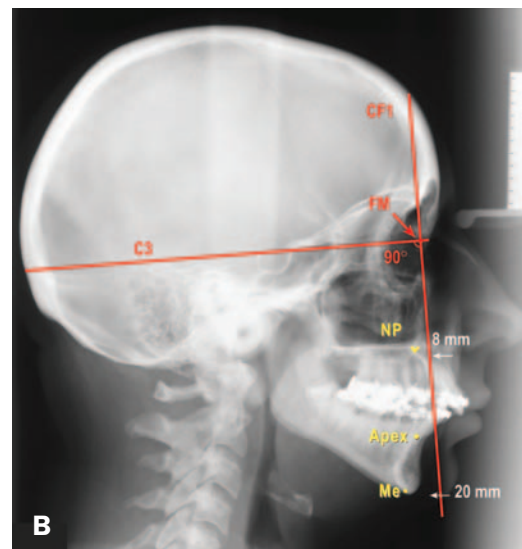
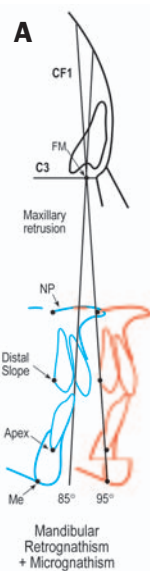


FIGURE 39-19 The Me point (menton). A, If the menton lies behind CF1 when the line passes through the apex of the lower central incisor tooth; then a genioplasty is required to advance the chin and associated muscles to improve the pharyngeal airway and achieve facial balance. B, Lateral cephalometric radiograph of the patient in Figure 39-1A, which reveals maxillary and mandibular deficiency and microgenia. Maxillary advancement of 8 mm is required, along with mandibular advancement in combination with a genioplasty to move the menton 20 mm. C, Postsurgery cephalometric radiograph of the same patient demonstrating normal facial balance. D, Postsurgery profile view.



Based on a visual treatment objective, the prediction tracing is completed and the definitive movements are decided before surgery. To guarantee that the movements are achieved during the operation, it is necessary to perform model surgery that accurately reproduces the planned surgical cuts. An intermediate splint is then fabricated to use intraoperatively to position the bone segments. With the use of rigid fixation, it is possible to advance the mandible the predetermined amount, fixate it with titanium plates and/or bicortical screws, and then advance the maxilla using the operated mandible as a guide (Figure 39-21). Conversely, the unoperated mandible can be used to position the maxilla in its new orientation, and the mandible is then repositioned secondarily (Figure 39-22). This is

the method of choice if the mandible requires a three-dimensional movement rather than a straight advancement.

When performing genioplasty, it is best to design the osseous cuts to allow for precision of movement, ease of repositioning, and placement of fixation to stabilize the mobilized osseous segment (Figure 39-23). The cut through the inner cortex should be high so that a portion of the genial muscles remains fixed to the advanced segment.

On occasion, the cephalometric radiograph will reveal constriction of the retropalatal airway; however, the maxilla cannot be significantly advanced and remain within the range of normal facial balance. In this case, an option is to perform a segmental Le Fort I osteotomy with the removal

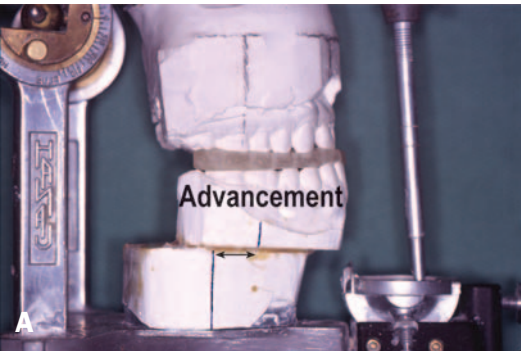


FIGURE 39-21 Mandibular advancement. *A*, Model surgery to control the advancement of the mandible. *B*, The mandible is fixated in a predetermined position using an intermediate splint. *C*, Rigid fixation of the mandible.

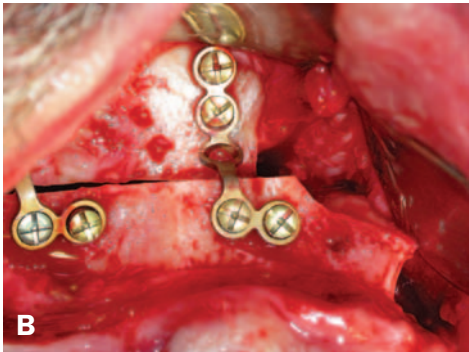
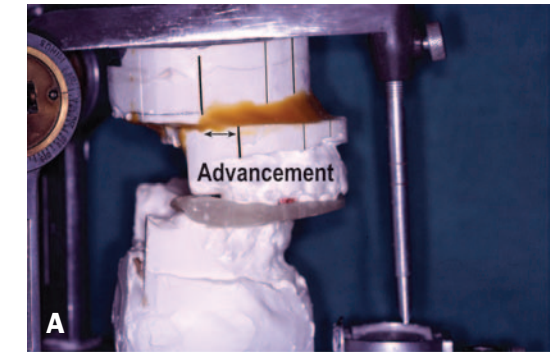


FIGURE 39-22 Maxillary advancement. *A*, Model surgery to control the advancement of the maxilla. *B*, Advanced maxilla.

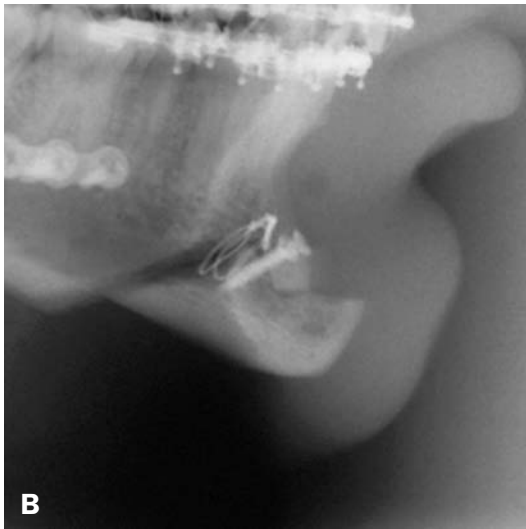
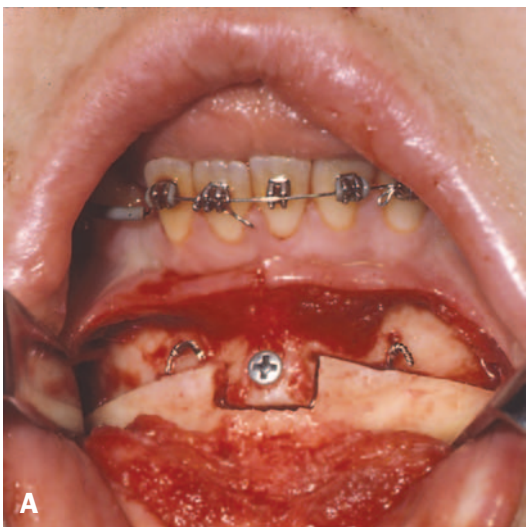


FIGURE 39-23 Genioplasty. *A*, Genioplasty using a tenon to control the advancement and aid in placement of rigid fixation. *B*, Radiograph demonstrating the lingual cut of the genioplasty to allow advancement of a portion of the genial muscles.

of a transverse segment of bone that contains the first bicuspid teeth. This will allow approximately a 7 mm advancement of the posterior maxilla, and its attached soft tissue in addition to the advancement allowed for the anterior segment to be positioned at 90 to 95° CF1/C3 (Figure 39-24).



FIGURE 39-24 Patient with severe obstructive sleep apnea syndrome. The cephalometric radiograph reveals constriction of both the retropalatal and retroglottal airways. Clinical examination reveals an acute nasolabial angle, and cephalometric analysis confirms that the maxilla can be advanced only 3 mm. The menton, however, can be moved anteriorly 13 mm. Model surgery confirms that the removal of a transverse segment of bone containing the first bicuspid teeth will allow a 7 mm advancement of the posterior maxilla in addition to the 3 mm advancement of the anterior segment, for an overall advancement of 10 mm of the posterior border of the hard palate. *A*, Pretreatment profile view. *B*, Pretreatment cephalometric analysis. *C*, Model surgery with the first bicuspid teeth removed and the posterior segment advanced. *D*, Articulated models used for an intermediate splint showing much greater advancement of the posterior segment compared with anterior movement. *E*, Intraoperative view of vertical osteotomy cuts to allow removal of the bony segment from the first bicuspid region. *F*, Intraoperative view of transverse cuts to allow removal of bone from the floor of the nose. *G*, Presurgical cephalometric radiograph confirming the surgical movement necessary to achieve facial balance and revealing the constricted oropharyngeal airway. *H*, Postsurgical cephalometric radiograph demonstrating that the surgical objectives have been achieved, with the patient having normal facial balance and the pharyngeal airway having improved significantly. *I*, Presurgical profile view. *J*, Postsurgical profile view.

When advancing the maxilla 10 mm or more, it is very common for the only bony contact to be in the regions of the zygomatic buttress and piriform aperture. To reduce the potential for fibrous

union, the surgeon can consider using local bone harvested from the mandible or chin and placed in the region of the large step that is created in the lateral wall of the maxilla (Figure 39-25). If bone

is not available, another option is to use blocks of hydroxyapatite in the same region (Figure 39-26). It is also very important to minimize the mobility of the maxilla during the initial healing phase.

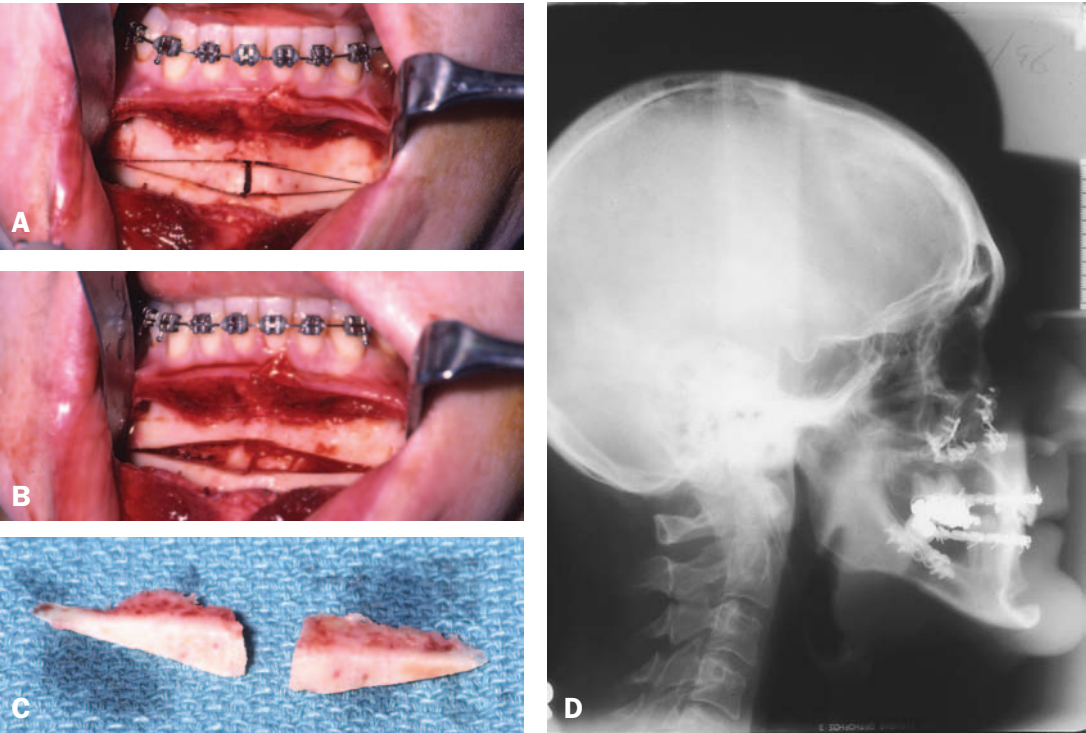


FIGURE 39-25 A, Bony cuts to allow harvesting of bone from the anterior mandible. B, Anterior mandible donor site. C, Bone stock from the chin. D, Cephalometric radiograph of a patient with obstructive sleep apnea syndrome following maxillomandibular advancement using bone harvested from the chin.

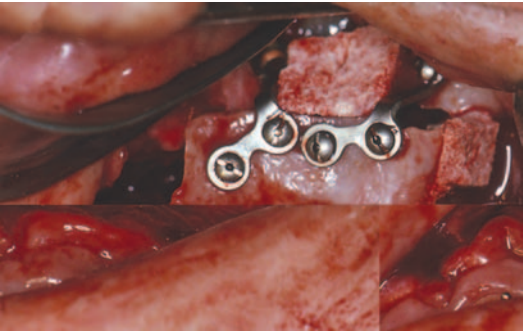


FIGURE 39-26 Blocks of hydroxyapatite placed behind the maxilla and in the region of the step produced following a significant maxillary advancement.

The bending of a bone plate that results in a long right angle span between the superior and inferior screw holes may result in flex or fracture of the plate that allows micromovement of the maxilla (Figure 39-27). This movement may promote fibrous union of the maxillary osteotomy site. A possible solution to this problem is the use of bicortical screws going from the down-fractured segment through the solid bone normally located in the zygomatic buttress region and/or in the anterior through the solid bone of the trigone region of the piriform aperture (Figure 39-28).

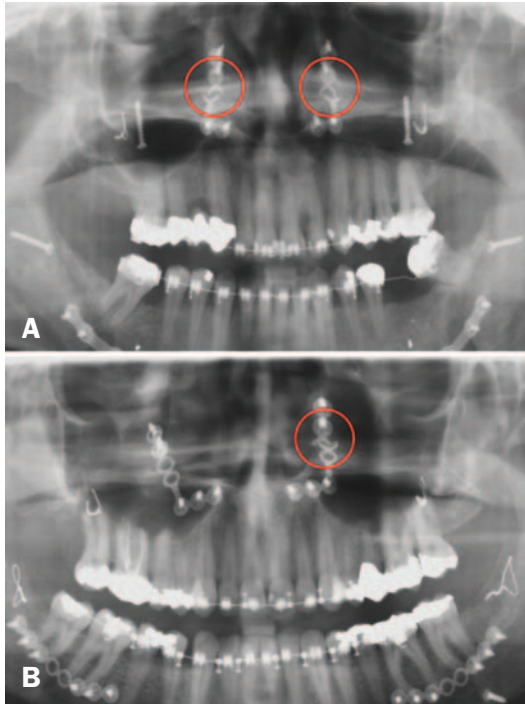


FIGURE 39-27 A and B, Fracture of anterior plates resulting from a long right angle span between the superior and inferior screw holes following a large maxillary advancement.

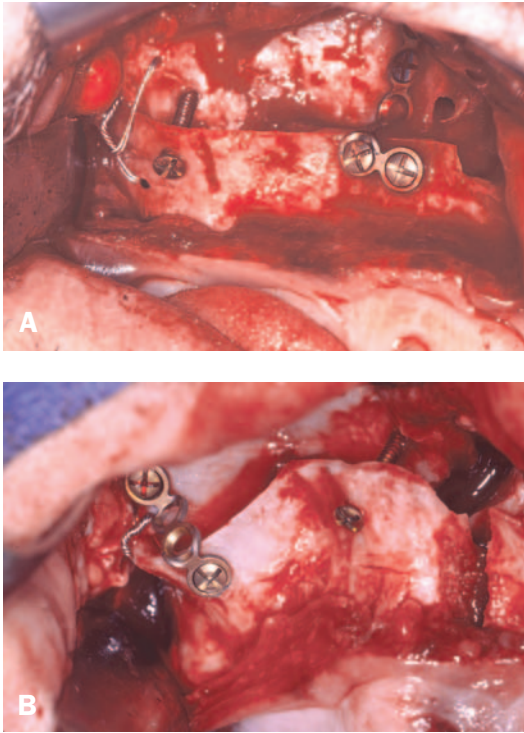


FIGURE 39-28 A, Bicortical screw in the zygomatic buttress region. B, Bicortical screw in the piriform aperture region.

Clinical Experience

Cases to illustrate the use of MMA to treat OSAS patients are found in Figure 39-29. The Delaire cephalometric analysis is used in each case to determine the advancements required for the maxilla and the mandible. Confirmation of achieving the planned surgical movements is observed by placing the presurgical cephalometric tracing over the postsurgical radiograph and noting the position of the anatomic landmarks to CF1. Ideally, the points (FM, NP, apex, Me) will fall on this line of anterior facial balance.

Using the Delaire analysis to plan surgical movements and performing precise surgery with fixation techniques as described appear to be very stable. Chiarot evaluated the preoperative and long-term postsurgery radiographs of 20 adult OSA patients who had undergone MMA using a combination of Le Fort I osteotomy and bilateral sagittal split osteotomy with or without advancement genioplasty.²³ The mean maxillary advancement at the Le Fort I level was 8.5 mm (range 3.2–11.8 mm). The surgical mandibular advancement at the sagittal ramus osteotomy was 11 mm (range 5.3–21.3 mm) and at the genioplasty site was 7.7 mm (range 3.3–13 mm). The mean relapse for the maxilla was –0.6 mm (range –2.7–0.5 mm). The average mandibular relapse was –1.1 mm (range –5.6–1.8 mm), and for the genioplasty, the average relapse was –0.45 mm (range –1.25–0.25 mm).

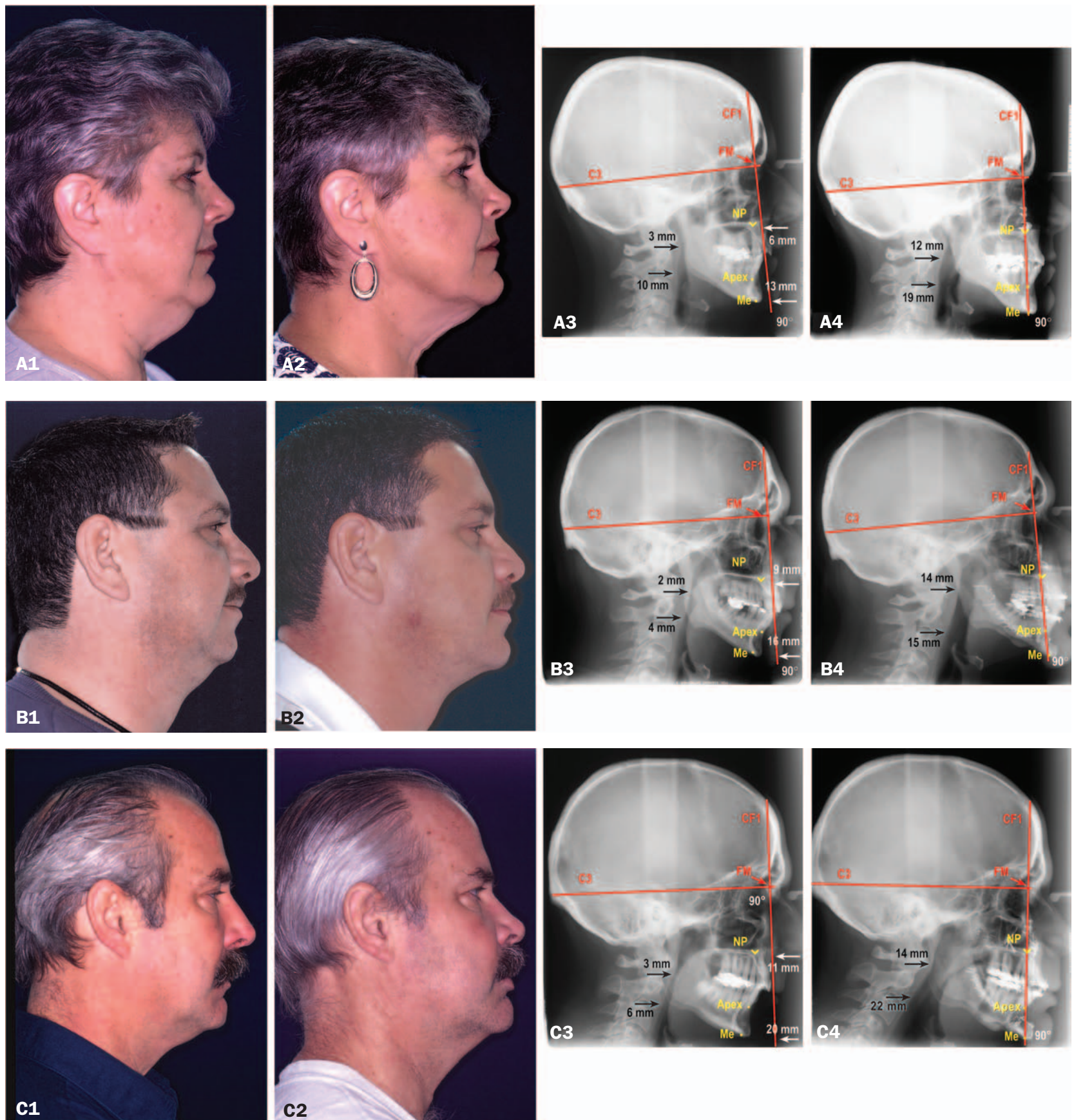


FIGURE 39-29 Patients with obstructive sleep apnea syndrome treated with maxillomandibular advancement using the Delaire cephalometric analysis to determine magnitude of movement of the maxilla and mandible. *A*, Female patient balanced at 90° CF1/C3. *B*, Male patient balanced at 95° CF1/C3. *C*, Male patient balanced at 90° CF1/C3. A1 to C1, Profile view presurgery. A2 to C2, Profile view postsurgery. A3 to C3, Presurgery cephalometric radiograph. A4 to C4, Postsurgery cephalometric radiograph. Note the significant improvement in the retropalatal and retropharyngeal airways and normal facial balance demonstrated by the alignment of points (FM, NP, apex, Me) on the line of anterior facial balance, CF1, following surgery.

Anesthetists often express concern about postoperative airway management in OSA patients requiring genial advancement for any surgical procedure. Some anesthetists have additional concern for OSA patients undergoing MMA and feel that edema will result in airway compromise. In assessing the radiographic changes in the pharynx of 25 consecutive OSA patients 24 to 48 hours following MMA, Robertson and colleagues found an increase in the mean distance from the posterior pharyngeal wall to the soft palate of 5.2 mm and a mean increase in the distance to the base of the tongue of 5.88 mm.²⁴ These results indicated that postoperative edema did not have any detrimental effect on the anteroposterior dimension of the pharyngeal airway of the sleep apnea patients undergoing orthognathic surgery.

These radiographic findings were supported on a clinical basis when Yim looked at perioperative pulse oximetry of MMA surgery for treatment of OSAS.²⁵ Pulse oximetry data presurgery were compared with data gathered over a 48-hour period immediately postsurgery in 19 patients. This group of patients had an average of 15.2 desaturations per hour before surgery, which dropped significantly to an average of 1.3 per hour during the 48 hours postsurgery (Table 39-2).

MMA increases the pharyngeal airway space postoperatively, and this is thought to be one of the reasons for the decrease in the AHI found during postoperative polysomnographic studies. Gregoire and colleagues conducted a study to determine if there is a correlation between the increase in the pharyngeal airway space and a decrease in the AHI.²⁶ Assessment of the pre- and postoperative cephalometric radiographs of 20 OSAS patients revealed a median increase in the retropalatal pharyngeal airway of 96% and an

increase of 108% in the retroglossal pharyngeal airway. In this group of patients, the mean decrease in the AHI was 73%. Interestingly, there was no correlation found between the increase in the retropalatal or retroglossal pharyngeal airway space and the decrease in AHI postoperatively. As the lateral cephalometric radiograph gives only a two-dimensional representation of the pharyngeal airway, it is reasonable to assume that changes in the medial-lateral dimension are also likely affected by MMA surgery in a favorable manner.

When looking at treatment outcomes in 20 OSA patients following MMA, Robertson found the following: in this group of patients, (1) the level of daytime sleepiness was reduced to that found in normal controls; (2) of the patients who snored preoperatively, 90% experienced a reduction in snoring, with 45% snoring less loudly and 45% no longer snoring at all; and (3) 83% of the patients felt that the surgery was worthwhile, 12% felt otherwise, and 5% were undecided.²²

Treatment by immediate lengthening of the maxilla and mandible is an option that should be considered for OSAS patients who have demonstrable retrognathia and narrowing of the pharyngeal airway. This option follows a principle based on scientific rationale rather than trial and error and in most cases will negate the need for multiple surgeries. MMA is a stable, predictable procedure that results in significant improvement and a high level of patient satisfaction in a short time frame.

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Table 39-2 Summary of Desaturation Index of 19 Maxillomandibular Advancement Patients		
Desaturation per Hour	OSAS	
	Mean	Range
Presurgery	15.2 ± 19.2	0.1-65.8
Night 1	1.3 ± 1.4	0.0-7.4
Night 2	1.3 ± 1.3	0.0-3.8
OSAS = obstructive sleep apnea syndrome.		

Minimally Invasive Orthognathic Surgery

Maria J. Troulis and Leonard B. Kaban

Until the mid-nineteenth century, operations were associated with high morbidity and mortality rates and were reserved only for life-threatening conditions. Surgical procedures were excisional in nature and carried out as rapidly as possible. A lack of understanding and an inability to manage pain, infection, hemorrhage, and shock were the factors limiting the discipline of surgery.^{1,2} With the development of anesthesia and aseptic technique and the discovery of antibiotics and the principles of fluid and electrolyte balance, surgery progressed so that elective procedures to improve the quality of life became feasible.¹⁻³

Hullihen reported the first orthognathic surgical procedure in the *American Journal of Dental Science* in 1849. This was a mandibular osteotomy for the correction of retrognathism and an anterior open bite resulting from a burn scar contracture of the neck. Hullihen appreciated the role of the soft tissue (ie, scar) in the development of the patient's skeletal deformity. He also realized that the scar had to be released prior to skeletal correction to ensure the stability of the result. The next successful orthognathic surgical operation, the "St. Louis procedure," was a collaborative effort between the orthodontist Dr. Edward Angle and the surgeon Dr. V.P. Blair. Bilateral ramus osteotomies were performed for the treatment of mandibular prognathism.⁴ In the early twentieth century, a variety of additional mandibular ramus procedures were described for the correction of prognathism.⁴⁻⁷

The first maxillary osteotomy (for correction of a malocclusion) was performed in 1921 by Gunther Cohn-Stock.⁸ Wassmund modified this osteotomy and popularized the technique.⁹ Little progress was made during World War II, and it was not until the 1950s that Trauner refined and modified existing maxillary osteotomy techniques and recognized the need for three-dimensional treatment planning.¹⁰ He also trained two great innovators of the field of orthognathic surgery: Heinz Kole and Hugo Obwegeser. In 1955, Trauner and Obwegeser described the sagittal split osteotomy of the mandible.¹¹ This was a

significant advance because the operation was performed intraorally and could be used for the correction of a variety of deformities, including prognathism, retrognathism, asymmetry, and open bite. Furthermore, a bone graft was not necessary when the mandible was advanced. Bilateral sagittal split osteotomy (BSSO) became the most commonly performed orthognathic surgical operation in the 1960s and 1970s and remains the mainstay of mandibular surgery to this day. Stable results with this operation have been reported for the correction of mandibular retrognathism, prognathism, asymmetry, and open bite.

In the 1970s and 1980s, orthognathic and craniomaxillofacial surgery progressed rapidly with improvements in anesthetic techniques, surgical instrumentation, and surgical exposure and improved understanding of the craniofacial anatomy and blood supply. Bell and Bell and Levy published fundamental studies delineating the blood supply of the maxillofacial skeleton.¹²⁻¹⁵ This work provided the biologic basis for orthognathic surgery. As a result of their research, maxillary orthognathic surgery became commonplace after the mid-1970s.

More recently, advances have been made to decrease the perioperative morbidity associated with orthognathic surgery.³ Spiessel, Champy, Luhr, and others are credited with the development of rigid internal fixation (RIF). RIF, controlled hypotensive anesthesia,¹⁶⁻¹⁹ administration of perioperative steroids,^{20,21} and patient positioning have decreased patient morbidity by eliminating the need for maxillomandibular fixation (MMF), decreasing blood loss or the risk of transfusion, decreasing edema, and decreasing discomfort. Furthermore, the combined effect of these techniques has decreased the length of hospital stay.²²

In the twenty-first century, advances in imaging, fiber-optic technology, and instrumentation will allow surgeons to develop and refine minimally invasive techniques to replace many traditional (maximally invasive) surgical procedures.² The impetus for minimally invasive surgery

comes from both patients and surgeons who appreciate the benefits of endoscopic techniques: less swelling, less pain, a shorter hospital stay, and an earlier return to work. This is cost-effective and "state-of-the-art medical care."²³

Distraction osteogenesis (DO) is a minimally invasive alternative to standard osteotomies and bone grafts for the correction of skeletal deficiency problems (eg, maxillary and mandibular hypoplasia or retrognathism). The endoscopic approach to the mandibular ramus-condyle unit (RCU) is a minimally invasive method of exposure to perform mandibular osteotomies and other reconstructive procedures and to place distraction devices, using very small access incisions. Minimally invasive techniques, such as DO and endoscopy, may allow orthognathic and other reconstructive procedures to be performed safely in an outpatient setting. This would have a significant impact on cost, availability, patient morbidity, and patient acceptance.

In this chapter, we present the use of DO and endoscopic exposure of the RCU as minimally invasive alternatives to standard orthognathic surgical techniques.

Distraction Osteogenesis

Background

DO is a technique that makes use of the body's ability to form new bone in response to tension across an osteotomy. Gradual bone lengthening also results in expansion of the overlying soft tissue. Surgical corrections of a greater magnitude than previously thought possible can be achieved with DO without the need for a bone graft. The risk of relapse may be diminished because of the gradual expansion and adaptation of the soft tissue envelope.^{24,25}

DO was first described in the orthopedic literature by Codivilla²⁶ and was later popularized by Ilizarov in the 1950s. Ilizarov studied DO clinically and experimentally using the canine tibia model.^{27,28} Long bone and craniomaxillofacial distraction protocols currently in use are mostly

based on the pioneering clinical and experimental data of Ilizarov.

In 1973, Synder and colleagues were the first to report the use of DO in the maxillofacial region.²⁹ A canine model was used to demonstrate the feasibility of mandibular expansion using DO. Mandibular lengthening by gradual distraction has similarly been demonstrated in other canine models.^{24,30}

In 1992, McCarthy and colleagues were the first to report on mandibular DO in humans.³² Using an external pin-retained orthopedic device, they successfully lengthened the mandible of four syndromic patients. The first report of DO to widen the mandible and simultaneously correct the intraoral soft tissue deficiency was by Perrott and colleagues.³³ DO has also been used to expand the maxilla in animal models³¹ and humans.^{34–36} Simultaneous distraction of the maxilla and mandible as a unit is an obvious extension of the technique and has also been reported.³⁷

Mandibular retrognathism resulting in Class II malocclusion represents approximately one-third of all dentofacial deformities in the United States. From 1979 to 1998, 56.7% of the patients evaluated in the Dentofacial Program at the University of North Carolina were diagnosed with skeletal Class II malocclusion. Almost all of these patients had mandibular deficiency in the sagittal plane; none had maxillary protrusion alone, and 2% were noted to have a combination of maxillary protrusion and mandibular deficiency.³⁸

The standard operation for correction of skeletal Class II malocclusion is the BSSO. The procedure remains one of the most commonly performed orthognathic operations, and the outcomes are very predictable. However, several limitations are associated with the BSSO. The most frequent adverse effect of the sagittal split osteotomy is altered sensation of the inferior alveolar nerve (IAN). This is in part a result of stretching and retraction of the nerve during the procedure. The patient awakens with paresthesia in the distribution of the IAN. Although the altered sensation is usually temporary and resolves within 2 to 6 months, 20 to 25% of patients have some degree of permanent deficit.^{39,40} Furthermore, neurosensory recovery in patients over 40 years of age is very poor.^{41–43} DO may allow for mandibular advancement with a decreased risk of IAN damage.⁴⁴

Skeletal and occlusal relapse are additional factors to consider when advancing the maxilla or mandible using standard techniques. The amount of relapse and resistance of the soft tissue envelope is related to the magnitude of advancement.^{45,46} In contrast, during DO, there is histogenesis of the soft tissue envelope, and this may contribute to a lower relapse rate.^{25,32}

Indications

The indications for mandibular distraction include retrognathism and retrognathism with a deep bite. Patients who have a third molar bud present, those who are hesitant to proceed with standard sagittal split osteotomy because of the risk of IAN damage (especially patients over the age of 40 years),^{43,47} and those who require a large advancement (greater than 8 mm) and who therefore might be at a higher risk of relapse with BSSO^{45,46} are excellent candidates for DO.

The indications for maxillary distraction include retrognathia and short anterior face height. Patients who would especially benefit from DO are those who require a large advancement (greater than 8 mm) and those who have significant soft tissue scarring (cleft lip or palate) from radiation therapy or multiple previous operations, which may prevent achieving the treatment goals with traditional Le Fort I osteotomy.

Surgical Techniques

Mandibular Distraction

The mucosal incision and dissection are similar to those for BSSO, but no medial dissection is required. A corticotomy is made through the third molar tooth bud extraction socket or posterior to the last existing tooth (usually the 12-year molar). The distraction device is placed across the corticotomy (Figure 40-1). For standard

orthognathic cases, the Dynaform distraction device is used (Leibinger, LP, Dallas, TX). This device is an intraoral, semicustom device. Intraoperatively, it is customized by adjusting the length and bends of the attachment arms that attach to the footplates. The wounds are closed, leaving the activating mechanism exposed transmucosally.⁴⁸

Maxillary Distraction

A horizontal vestibular incision is made extending from the 12-year molar to the contralateral 12-year molar. Alternatively, bilateral vestibular incisions are made from the 12-year molar to the canine regions and a vertical incision is made to expose the anterior nasal spine and nasal septum. The mucosa overlying the premaxilla is left intact. The lateral piriform apertures, anterior maxilla, and zygomaticomaxillary buttress regions are exposed. Osteotomies are made from the piriform rim through the zygomaticomaxillary buttresses to the pterygoid plates. The plates are separated from the maxilla, the lateral nasal wall is osteotomized, the nasal septum is separated, and the maxilla is mobilized but not down-fractured. A Le Fort distraction device, which is semiburied (KLS Martin, Kalamazoo, MI; Synthes Maxillofacial, Paoli, PA), is placed and secured across the osteotomy. The wounds are closed, leaving the activating mechanism exposed transmucosally (Figure 40-2).

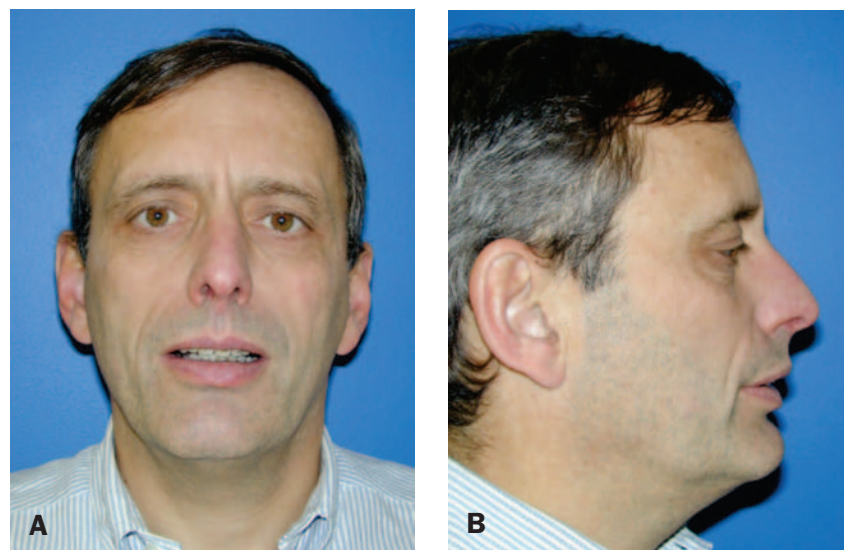


FIGURE 40-1 Distraction osteogenesis: mandibular advancement. Frontal (A) and lateral (B) photographs of a 54-year-old male patient with mandibular retrognathia and a deep mentolabial fold.



FIGURE 40-1 continued C, Intraoral photographs. D and E, Note the overjet and deep overbite. Intraoperative views of distraction devices. The Dynaform device is seen in its stock form (D, top). Then bend and footplates are attached, customizing the device for the patient (D, bottom). The footplates to be placed on the proximal fragment have a notch in them, making the device detachable. E, The prebend device is seen secured across the vertical osteotomy. The osteotomy is made just behind the last molar (12-year molar). The two proximal footplates are secured with 7 mm–long, 2.0 mm–diameter screws. The top distal footplate is secured via a circumferential wire to the premolar and the bottom distal footplate is secured to the bone with a transmucosal screw. Radiographs at the end of distraction osteogenesis: right (F) and left (G) panoramic views and a lateral cephalogram (H); frontal (I) and lateral (J). The devices are barely noticeable. Note the correction of the deep mental labial fold. Intraoral (K) and lateral (L) cephalogram at the 6-month follow-up, after completion of orthodontia. On the radiograph, note the screws that remain when the device is removed.

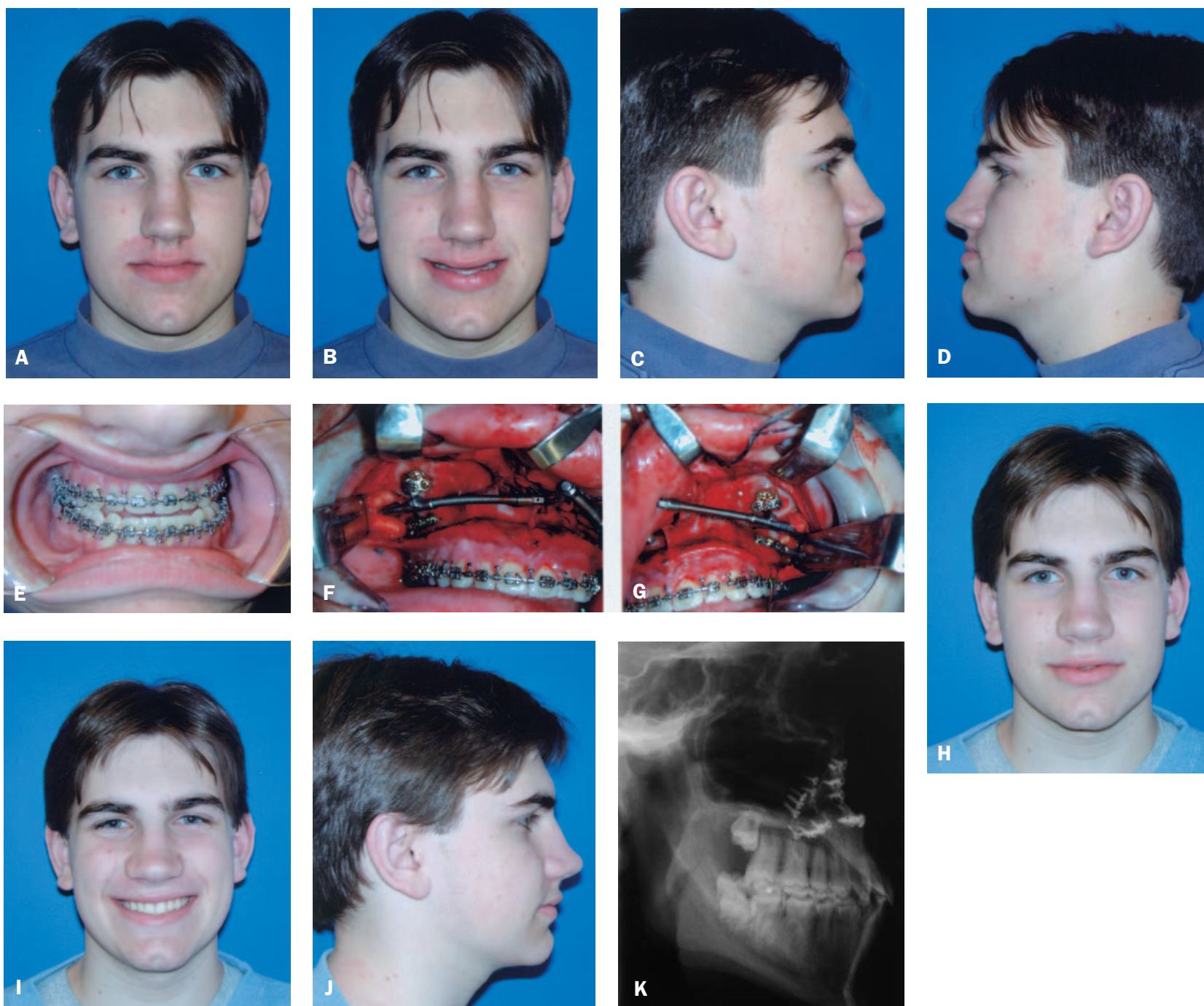


FIGURE 40-2 Distraction osteogenesis: maxillary advancement. Frontal rest (A) and frontal smiling (B) photographs of a 15-year-old male patient with maxillary retrognathia. Note the lack of perinasal soft tissue support and the lack of teeth showing on smiling. Right lateral (C) and left lateral (D) photographs. Note the lack of perinasal soft tissue support and maxillary retrognathia. E, An intraoral photograph shows the anterior crossbite. F, Intraoperative photograph. A Le Fort osteotomy had been made from the piriform rim and extends across the anterior maxillary wall, wraps around the buttress, and ends at the pterygoid plates. Pterygomaxillary disjunction is performed; the maxilla is mobilized but not down-fractured G, The device (KLS Martin, Le Fort distractor) is secured across the osteotomy. Frontal rest (H) and frontal smiling (I) photographs after the completion of orthodontia. Note the adequate number of teeth showing. Lateral photograph (J) and lateral cephalogram (K) at the same time point. On the radiograph, note the rigid fixation plates. For comfort, the device was removed early and rigid fixation plates were used. K, Intraoral photographs show the final occlusion.

Distraction Protocol

After a 2- to 4-day latency period, distraction is performed at a rate of 1 mm/d in divided doses (two or four times per day) and continued until the desired advancement is achieved. The neutral fixation period is usually set individually for each patient based on clinical, plain radiographic, and ultrasonographic evidence of bone bridging across the defect. The average period of neutral fixation is approximately 6 to 8 weeks.

Outcomes

In a retrospective evaluation of 20 patients who underwent mandibular advancement via a BSSO ($n = 10$) or DO ($n = 10$), it appears that sensory nerve alteration was less frequent when DO was performed. Furthermore, an increase in vertical dimension (anterior face height) appeared to be more stable with DO.⁴⁴ Prospective studies are currently underway.

Endoscopic Procedures

Background

The benefits of endoscopy include small and remotely placed incisions, acceptable hidden scars, and direct visualization of a magnified and illuminated operative field. Minimal tissue dissection and manipulation result in less edema⁴⁹ and morbidity.^{50–52} The length of hospital stay is shorter,^{50,52} and patients return more quickly to normal activities.

Recently, there has been great interest in the development of endoscopic techniques for exposure and reconstruction of the craniomaxillofacial skeleton.^{53–56} We chose to use a small extraoral submandibular incision for access to the RCU. This approach significantly reduces the manipulation and soft tissue trauma during the dissection and exposure and reduces bleeding and swelling because of the well-contained and localized nature of the optical cavity. The surgeon is able to visualize the operative field en face, which is the most comfortable orientation from which to operate, teach, and learn. The patient can be placed in MMF prior to fixation without compromising access.^{50–52}

Indications

Endoscopic vertical ramus osteotomy (EVRO) is indicated for patients with mandibular prognathism who refuse MMF (as is necessary with the intraoral vertical ramus osteotomy [IVRO]) and who will not accept the high risk of IAN injury (ie, BSSO). The procedure is also indicated for older patients with mandibular prognathism

and deeply impacted asymptomatic wisdom teeth because the risk of IAN damage is less than with BSSO.^{47,57} For patients with mandibular retrognathism and open bite secondary to idiopathic condylitis (condylar resorption) or degenerative joint disease, endoscopic condylectomy and costochondral graft (CCG) reconstruction is a minimally invasive alternative to the standard incisions for access.

Surgical Techniques

Endoscopic Vertical Ramus Osteotomy

Surgical technique. A 1.5 cm incision is made one fingerbreadth below the angle of the mandible parallel to the neck creases. The dissection is carried bluntly to the masseter muscle. The muscle is incised with a needlepoint electrocautery. The bone is exposed and the dissection completed in the subperiosteal plane using endoscopic elevators with a suction port (Snowden-Pencer, Tucker, GA). The subperiosteal dissection results in the optical cavity. The position of the incision and mobility of the soft tissue in this region allow the 2.7 mm–diameter, 30° Hopkins endoscope (Karl Storz, Carver City, CA) to be placed in the wound and to be oriented parallel to the posterior border with direct access to the entire RCU.^{50,51}

Anatomic landmarks of the RCU are identified: the posterior border, sigmoid notch, coronoid process, anterior border, and posterior body. A curved, long-handled retractor is positioned to maintain the optical cavity (Synthes Maxillofacial). Irrigation is performed through the endoscope irrigation port.^{50,51}

With endoscopic visualization, an osteotomy is created from the sigmoid notch to the mandibular angle using a long-shaft reciprocating blade (MicroAire Surgical Instruments, Charlottesville, VA) (Figure 40-3). The medial pterygoid muscle is partially stripped to allow overlap of the proximal and distal segments. When required, a clamp is used to control the proximal segment. The patient is placed into wire MMF in the desired, preplanned occlusion. Three 12 to 14 mm–long, 2.0 mm–diameter screws are used to secure the proximal and distal segments into position (through four cortices). Alternatively, if there is minimal overlap, plate fixation may be used. Screw holes are drilled, and screws are placed through the incision or with the aid of a percutaneous trocar.^{50,51}

Outcomes. In a recent, retrospective analysis, 14 patients (mean age 28 years; 9 males and 5 females) had successful EVROs and rigid

fixation ($n = 23$ sides).⁵¹ The mean operative time was 37 minutes per side. In all cases, the procedure was executed via a 1.5 cm incision, the desired, preplanned occlusion was achieved, and rigid internal fixation was successfully applied through the working port (trochar access was not required). No patients required MMF.

One patient had marginal mandibular nerve weakness (lasting less than 1 week). None of the patients suffered any sensory changes related to the IAN. Thirteen patients had a hospital stay of less than 1 day. One patient, with concurrent medical problems, had a hospital stay of 2 days.

Proper positioning of skeletal segments was documented by lateral and posterior-anterior cephalograms and panoramic radiographs immediately postoperatively. The planned occlusal position was confirmed by clinical examination and by comparison with the articulated surgical models. Nine patients with mandibular prognathism ($n = 9$) had a mean setback of 4.7 mm (range 2–9 mm); the other five patients had an asymmetry. Lateral cephalograms at a mean of 1.7 years postoperatively (range 6 months to 2 years) documented the stability of the bone position.⁵¹

Condylectomy and Costochondral Graft

The standard technique for CCG reconstruction involves preauricular and submandibular incisions.^{58,59} In contrast, minimally invasive access is achieved with a 1.5 cm submandibular incision located in the skin folds of the mandibular angle.⁵² This approach results in small and inconspicuous facial scars, eliminates risk to the frontal branch of the facial nerve, and reduces dissection, tissue manipulation, bleeding, and swelling, which may result in a faster recovery. This has resulted in excellent patient acceptance of the technique.⁵²

Surgical technique. At the start, it is critical to identify and draw the surface landmarks: the zygomatic arch, temporomandibular joint, mandibular posterior border, angle, inferior border, antegonial notch, anterior border of the ramus, and sigmoid notch. The same 1.5 cm incision and dissection as described for the vertical ramus osteotomy is made. With the endoscope in place, bony anatomic landmarks of the RCU are identified, and in the case of the condylectomy procedure, the endoscopic view of the RCU allows the condylar head and neck to be readily dissected from the surrounding soft tissues. To facilitate the dissection, the RCU is distracted inferiorly with a traction wire (placed at the angle). The condylectomy is performed from the sigmoid

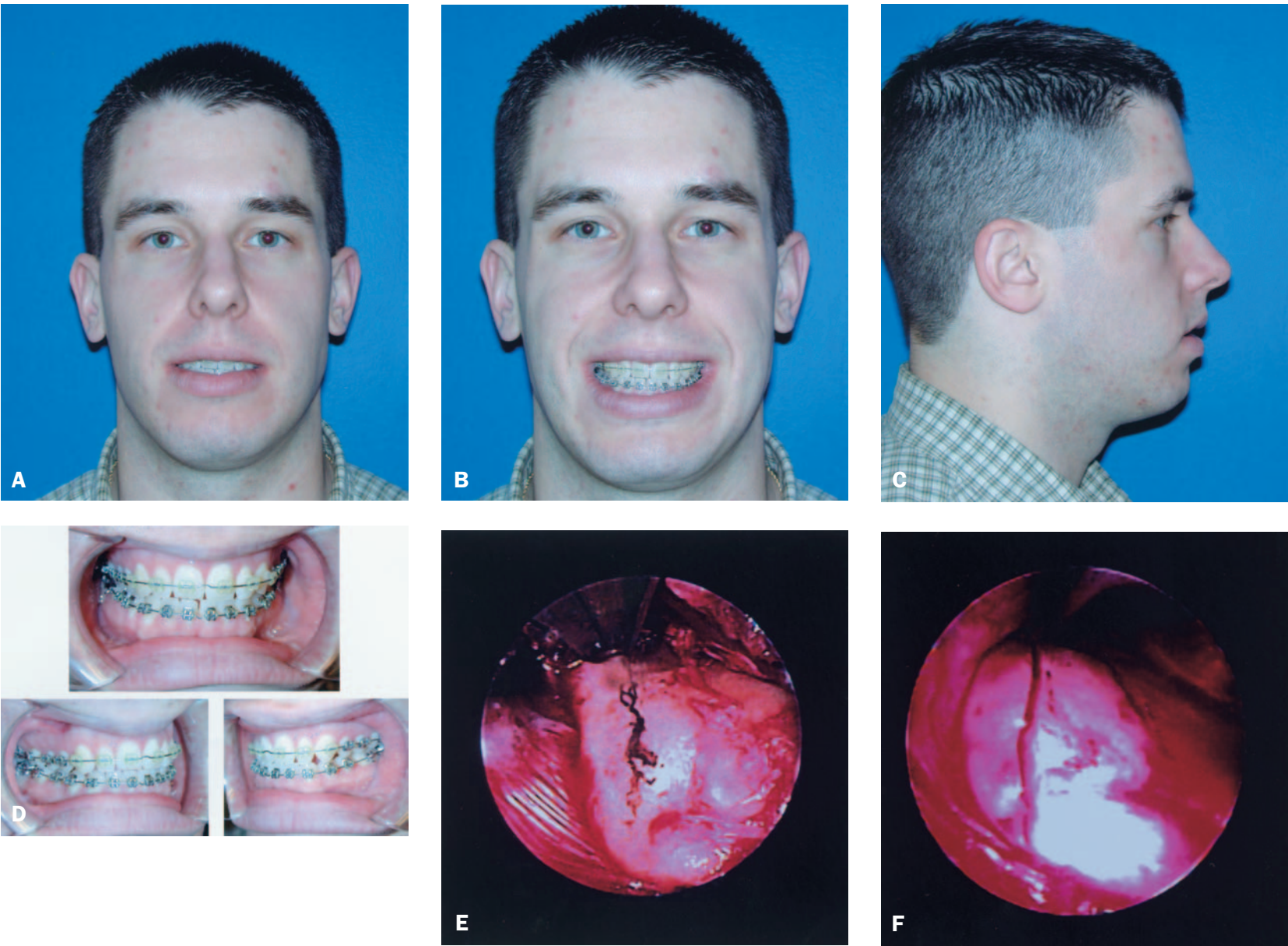


FIGURE 40-3 Endoscopic vertical ramus osteotomies. Frontal rest (A), frontal smiling (B), and lateral (C) photographs of a 20-year-old male patient who had a late growth spurt after completing orthodontia with resultant mild asymmetry (chin slightly deviated to the right) and a relatively orthognathic profile. D, Intraoral photographs document the edge-to-edge occlusion and mandibular asymmetry. Owing to the minimal deformity, it was elected to proceed with single jaw (mandibular) surgery. The endoscopic vertical ramus osteotomy was chosen to avoid maxillomandibular fixation and to minimize the risk to the inferior alveolar nerve. Endoscopic views of the proposed (E) and completed osteotomy (F).

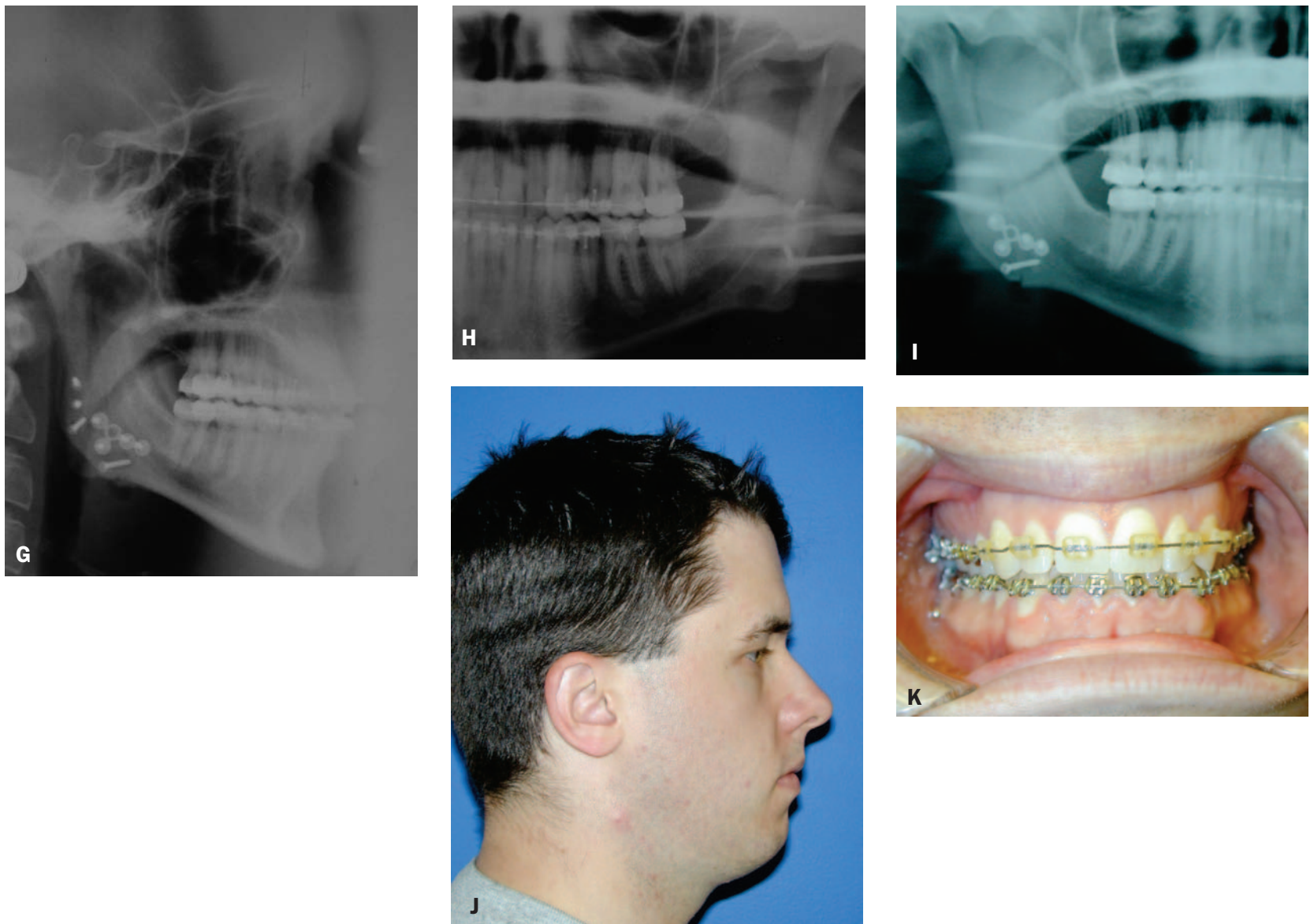


FIGURE 40-3 continued The immediate postoperative lateral cephalogram (G) and left (H) and right (I) panoramic radiographs demonstrate that the setback rotation was achieved and rigid fixation was placed. Note that on the right side (I), where rotation occurred, plate fixation supplemented with a single bicortical screw was used. On the left (H), three bicortical screws were used to fix the segments. The same patient shown 6 months postoperatively. The lateral cephalogram (J) confirm the inconspicuous, well-healed incisions. (K) shows the planned overjet, overbite, and coincident midlines. E, F, H, J, and I reproduced with permission from Troulis MJ and Kaban LB.⁵¹

notch to the posterior border of the mandible (Figure 40-4) using a long-shafted reciprocating blade (MiroAire, Charlottesville, VA). Skeletonization of the condyle is completed, and it is atraumatically removed. The undersurface of the articular disk is visualized.⁵² The patient is placed in MMF with a splint producing a 2 to 3 mm posterior open bite on the sides to be reconstructed with a CCG. This compensates for loss of vertical height (settling) of the CCG during healing and remodeling.^{58,59,60}

Costochondral grafts are harvested in the standard manner through an inframammary incision. Then, using the endoscope for direct visualization, the disk is identified and the CCG is

placed into the fossa. The graft is fixed in position using a 2.0 mm titanium miniplate, which acts as a washer, and three to five 12 to 14 mm-long, 2.0 mm-diameter screws (Synthes Maxillofacial). Screw placement is accomplished through the incision or with the aid of a percutaneous trocar.

Outcomes. In a retrospective evaluation by Troulis and colleagues, 10 females, with a mean age of 32 years (range 19–46 years), underwent successful endoscopic CCG reconstruction of the RCU ($n = 17$ sides).⁵² The mean operating time was 52 minutes (range 25–75 minutes) per mandibular side exclusive of the rib-harvesting procedure. The average length of stay for all patients

was 2.5 days (range 2–4 days). In all cases, the procedure was executed via the 1.5 cm incision. The desired, preplanned occlusion was achieved, and rigid internal fixation was successfully applied through the working port (trocar access was not required). All patients were placed in intermaxillary fixation for 10 to 14 days (to allow for initial graft healing).⁵²

None of the patients suffered any long-term neurologic changes related to the inferior alveolar, lingual, or facial nerve (mean follow-up 17 months; range 8–38 months). All patients demonstrated good range of motion both postoperatively and at follow-up. Maximal incisal opening returned to preoperative values by 1 year.

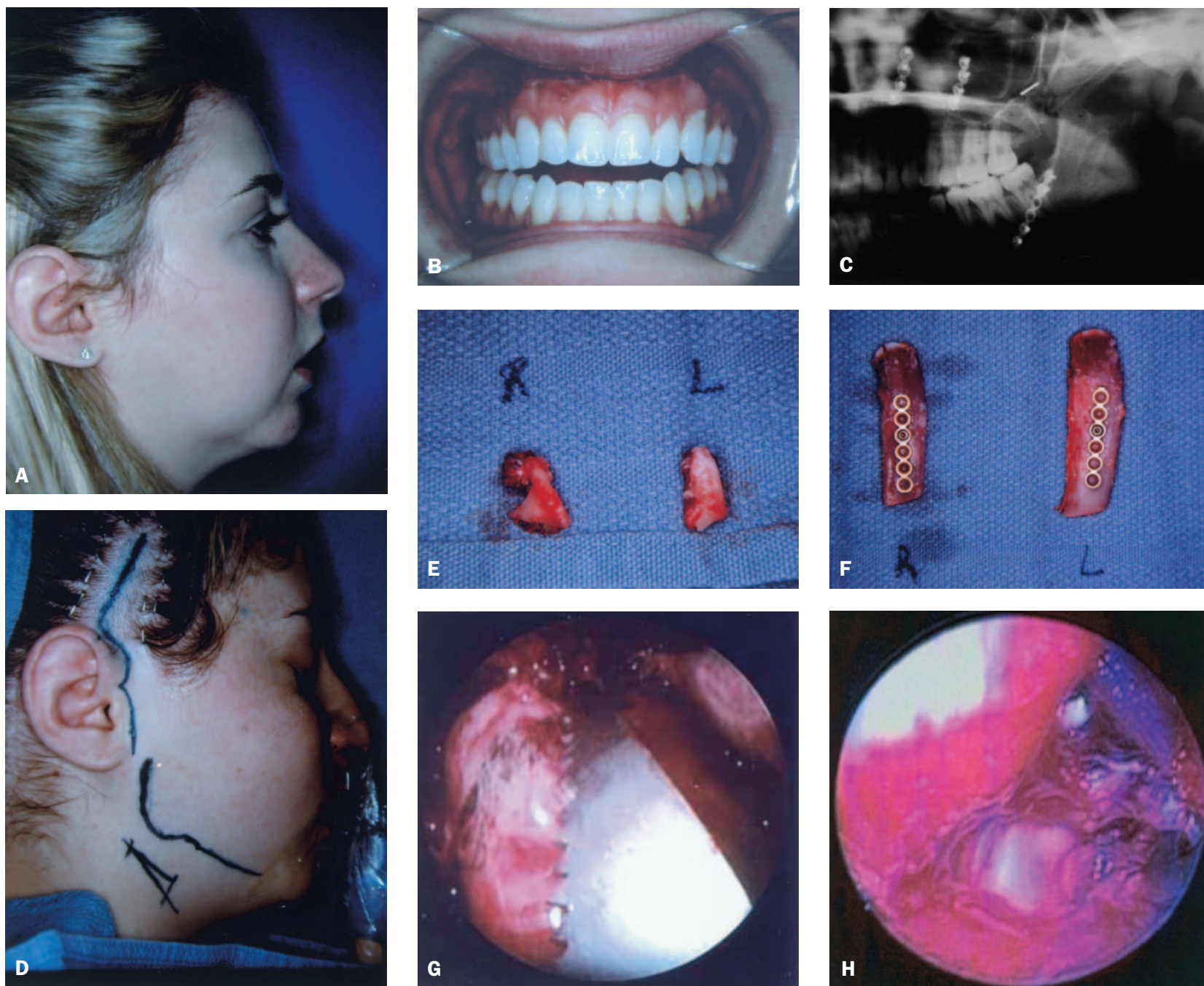


FIGURE 40-4 Endoscopic condylectomy and reconstruction. Lateral (A) and intraoral (B) photographs of a 25-year-old female patient with mandibular retrognathism, clockwise rotation of the mandible, and resultant open-bite malocclusion secondary to idiopathic condylar resorption. C, The panoramic radiograph demonstrates the resorbed left condylae and hardware from previous orthognathic surgery. D, The intraoperative lateral view demonstrates the standard incisions and the smaller endoscopic submandibular incision marked. The condylectomy specimens (E) and costochondral rib grafts (F) are shown intraoperatively. Endoscopic views of the right condyle, the proposed osteotomy, and the saw making the cut (G); the disk visualized prior to rib placement (H); and the costochondral graft placed against the disk and fixed into position with 2.0 mm screws.



FIGURE 40-4 continued Lateral (J) and intraoral (K) photographs of the patient 2 years after treatment. A, B, C, D, E, F, G, I, J, and K reproduced with permission from Kaban LB.² H reproduced with permission from Troulis MJ et al.⁵²

In all of the patients, the desired occlusion was obtained and maintained at the latest follow-up (average 17 months; range 8–38 months).⁵²

Discussion

During the last 25 to 30 years, minimally invasive techniques have been developed for gynecologic and urologic surgery and subsequently for general, cardiovascular, otolaryngologic, and facial esthetic surgery.⁵⁰ Only in the past decade have oral and maxillofacial surgeons begun to develop minimally invasive (endoscopic) techniques for correction of facial soft tissue⁶¹ and skeletal deformities^{50–56, 62} and diseases of the salivary glands.⁶³

The benefits of endoscopy include small and remotely placed incisions, acceptable scars, and direct visualization of an illuminated and magnified operative field. Minimal dissection and tissue manipulation result in decreased pain and swelling, less overall morbidity, and faster recovery. For these reasons, minimally invasive surgery has gained enthusiastic public acceptance.⁵⁰

Development and refinement of mandibular and midface endoscopic techniques for exposure, creation of osteotomies, and placement of distraction devices is ongoing. In the case of DO, miniature, totally buried, remotely activated distraction devices capable of accurate three-dimensional movements are desirable. These devices could be placed endoscopically.⁶² Finally, tissue engineering techniques will be used in the future to construct autologous bone grafts, and donor-site morbidity will be eliminated.^{64,65} The

marriage of these minimally invasive techniques (endoscopy, DO, and tissue engineering) may allow maxillofacial skeletal correction to be routinely performed under local anesthesia with intravenous sedation in an outpatient setting. This would have a significant impact on cost, patient morbidity, and availability of treatment.³

Acknowledgments

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Reconstruction of the Ramus-Condyle Unit of the Temporomandibular Joint Using Transport Distraction

Harry C. Schwartz

Most surgical procedures for the correction of dentofacial deformities require an intact temporomandibular articulation. Defects of the ramus-condyle unit (RCU) of the temporomandibular joint (TMJ) must be reconstructed to properly address these deformities. Indications for RCU reconstruction include tumor resection, irreparable condylar injuries, severe degenerative joint disease, idiopathic condylar resorption, ankylosis, congenital anomalies, and iatrogenic changes following previous TMJ surgery. The goals of RCU reconstruction include restoration of the height of the mandibular ramus, normalization of the occlusion and of TMJ function, freedom from pain, and long-term stability. In some instances, standard orthognathic surgical procedures will be needed to complete the case following RCU reconstruction.

Autogenous grafts have long been the “gold standard” for RCU reconstruction. They are immunologically compatible. They may be capable of continued growth and remodeling.

Donor sites can be chosen to match the ramus, condyle, or meniscus. Nevertheless, difficulties can be associated with autogenous grafting. A second operative site is required. There can be donor-site morbidity. Immobilization of the jaws is often required, which is inconvenient to the patient and can result in decreased range of motion. The occlusion can be unstable owing to resorption or overgrowth of the graft. Heterotopic bone can form, leading to ankylosis.

Prosthetic TMJ reconstruction has been advocated in an effort to prevent donor-site problems, decrease operating time, and maintain occlusal stability. Implants for the condyle, meniscus, and glenoid fossa have all been developed. Unfortunately, TMJ prostheses have had a history of design flaws, leading to mechanical failure and breakdown of the articular surfaces. Wear debris elicits a foreign body reaction, which can result in degenerative changes. Even successful TMJ prostheses do not have a life span approaching

that of the common orthopedic joint replacements, and episodic revision surgeries may be needed. Many patients have persistent pain and hypomobility.

In response to the difficulties encountered with both autogenous grafting and prosthetic reconstruction, distraction osteogenesis (DO) has been applied to reconstruction of the RCU.^{1,2} DO is well understood as the formation of new bone between living osseous surfaces that are incrementally separated. Although Ilizarov described the principles of DO in the decades following the Second World War,³ it has actually been practiced in orthopedics for centuries as traction and the manipulation of fractures. It has been practiced in dentistry for decades as rapid palatal expansion.

Transport DO is a classic Ilizarov technique for reconstruction of large segmental osseous defects. A transport disk is created from the distal margin of bone at one side of a defect (Figure 41-1). The disk is slowly transported toward the bone at the opposite side of the defect. Osteogenesis takes place at the trailing edge of the transport disk, whereas a cap of fibrocartilage forms at the leading edge (Figure 41-2). This latter phenomenon can cause difficulty in final closure of the defect, and the cartilage usually must be excised so that the bone can fuse. The phenomenon is used to advantage in RCU reconstruction. A transport disk is fashioned from the ramus or angle of the mandible (Figure 41-3). This becomes the new condyle. As it is slowly moved into the glenoid fossa, regenerate bone forms at the trailing edge. This becomes the new ramus or condylar neck. Fibrocartilage forms at the leading edge. This becomes the new articular surface. In this case, the cartilage is not excised (Figure 41-4).

Preoperative Case Planning

The workup for RCU reconstruction begins with a careful clinical evaluation to document

the preoperative condition. Records of the occlusion and of TMJ function are needed for every patient. Several imaging studies may be needed, depending on the underlying diagnosis. A panoramic radiograph and a high-resolution

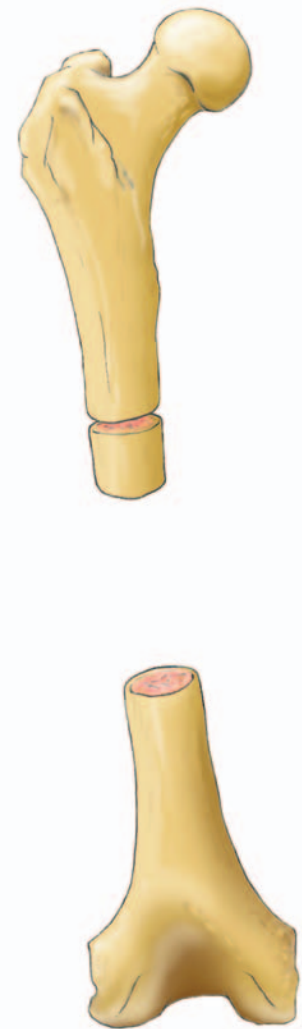


FIGURE 41-1 Transport distraction osteogenesis is used to reconstruct a segmental defect in the femur. First, a transport disk is cut in the bone at one margin of the defect.

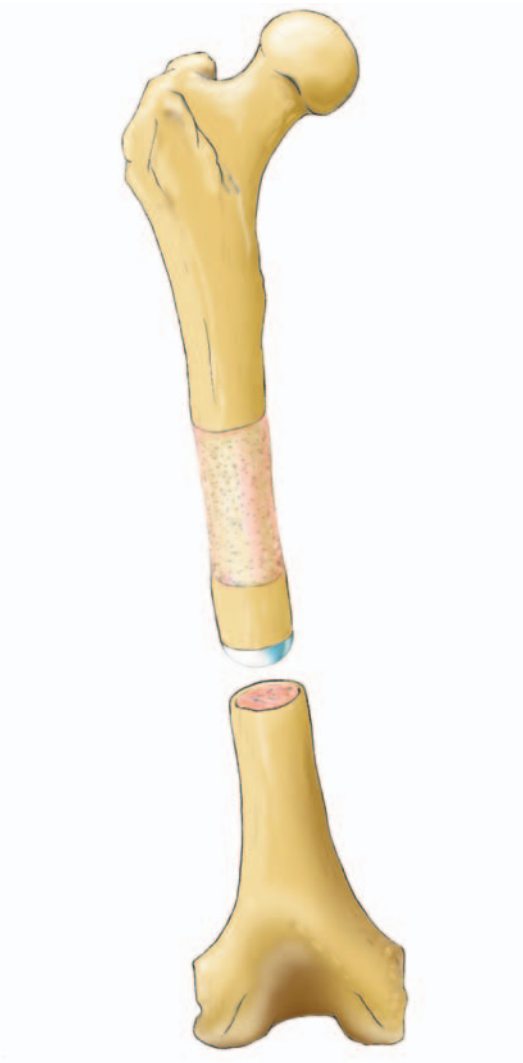


FIGURE 41-2 As the disk is slowly advanced across the defect, bone forms at its trailing edge and fibrocartilage forms at its leading edge. When the disk approaches the opposite margin of the defect, the cartilage must be excised. Bone can then form at the leading edge, and the defect is bridged.

computed tomographic scan are obtained for all patients (Figures 41-5 and 41-6). Such a scan can be reformatted in all planes of space (Figure 41-7), as well as three-dimensionally (Figure 41-8). It can be used to produce an exact stereolithographic acrylic model to study more complex cases and to customize distractors. Cephalograms are useful for some patients, especially when an underlying malocclusion is to be treated after RCU reconstruction. Radionuclide bone scans and magnetic resonance imaging are helpful in the preoperative evaluation of selected cases, particularly tumors and idiopathic condylar resorption.

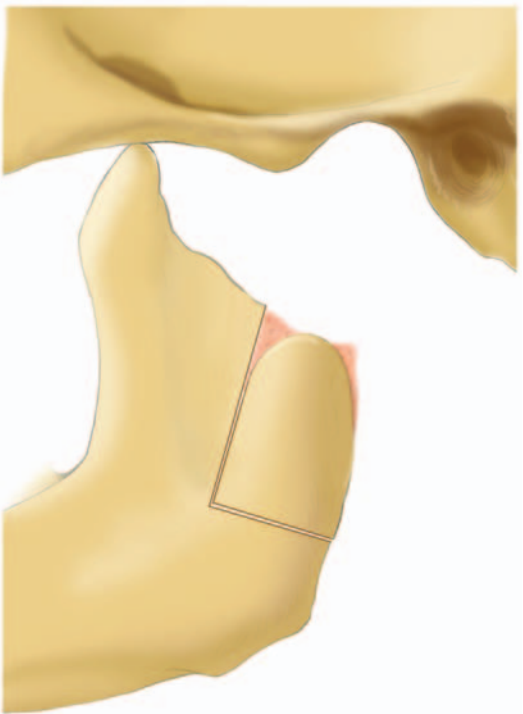


FIGURE 41-3 To reconstruct the ramus-condyle unit of the mandible, a transport disk is cut in the posterior ramus or angle.

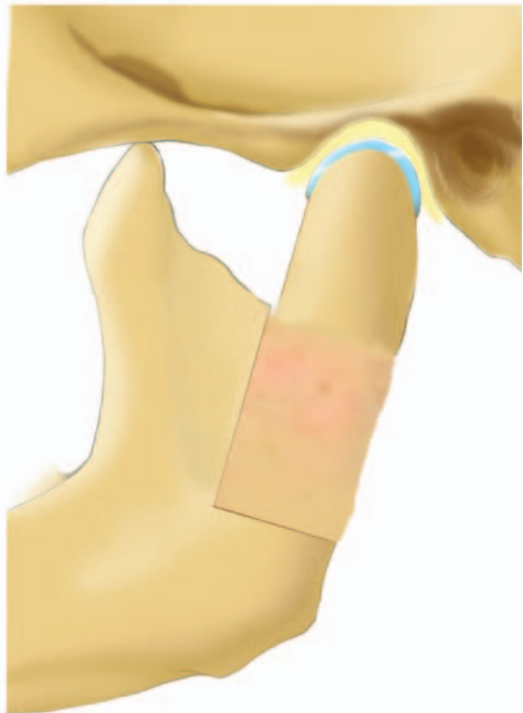


FIGURE 41-4 The disk is slowly advanced toward the glenoid fossa, with bone forming at the trailing edge and fibrocartilage at the leading edge. The cartilage is not excised as it will form a new articular surface.



FIGURE 41-5 Panoramic radiograph of a patient with a large unicystic ameloblastoma of the upper ramus, condyle, and coronoid process.



FIGURE 41-6 Computed tomographic scan of a patient with ankylosis of the right temporomandibular joint. The axial view shows medial attachment to the skull base, which is important to completely excise.



FIGURE 41-7 Computed tomographic scan of a patient with a large osteochondroma of the temporomandibular joint. Coronal reformatting details the medial extension, involvement of the upper ramus, remodeling of the glenoid fossa, and canting of the entire mandible.

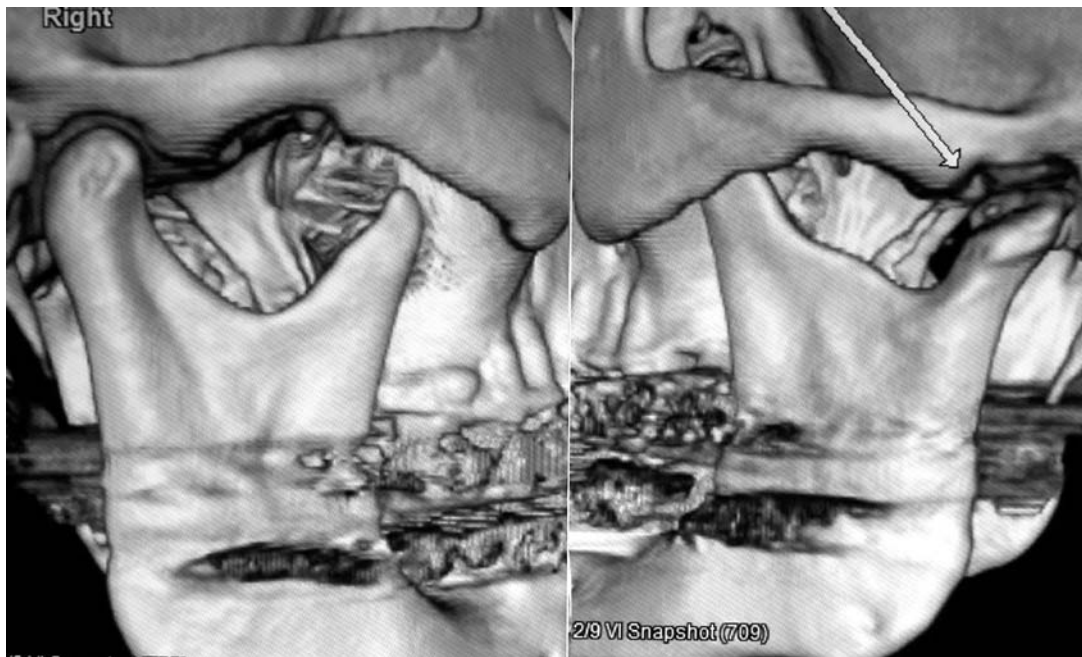


FIGURE 41-8 Three-dimensional reconstruction of a computed tomographic scan demonstrates marked degenerative changes in a patient following multiple failed left temporomandibular joint surgeries.

Surgical Technique

- The basic surgical approach is through a small incision below the angle of the mandible (Figure 41-9).
- This is usually combined with a second incision, depending on the patient's diagnosis (Figure 41-10). Condylectomy can generally be carried out via the standard preauricular approach to the TMJ. In the case of certain tumors or of ankylosis, an extended preauricular or a hemicoronal approach is preferred for improved access and to permit coronoidotomy or elevation of a temporalis flap.
- Wherever possible, the articular disk is left in the joint space.
- No preparation of the glenoid fossa is necessary, except in cases of ankylosis when a new fossa must be created. A great advantage to the use of this technique in the management of ankylosis is that thorough removal of heterotopic bone is possible. This includes bone on the medial aspect of the ramus, which might otherwise be difficult to approach. The large gap that is created is then reconstructed so that a malocclusion does not result. The surgical treatment of ankylosis of the TMJ is beyond the scope of this chapter.
- After the underlying pathology has been managed, the entire lateral ramus and angle are exposed. Care is taken to maintain all muscle and periosteal attachments on the medial side of the ramus.

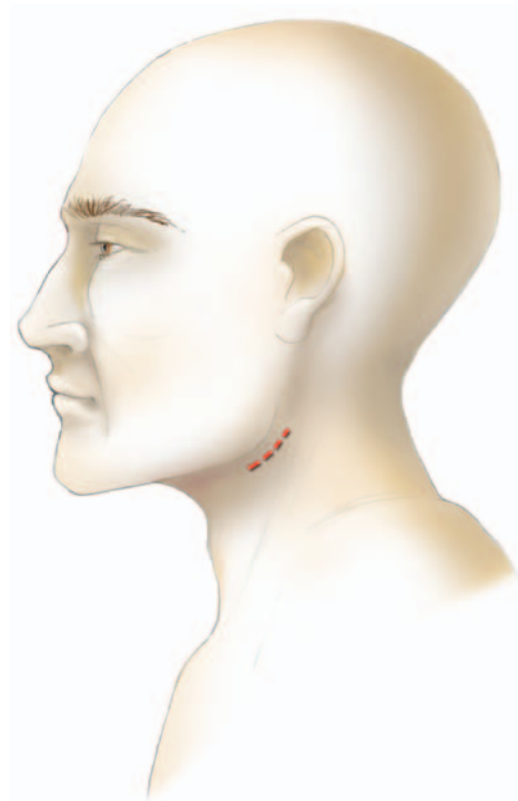


FIGURE 41-9 A small incision beneath the angle of the mandible provides access for creation of the transport disk and placement of a distractor.

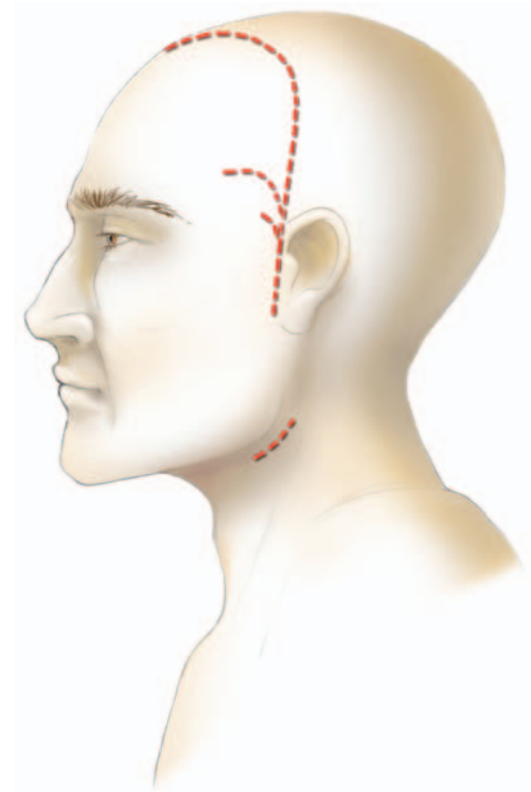


FIGURE 41-10 In most cases, simultaneous resection of some pathology is necessary. This is often done using one of the standard approaches to the temporomandibular joint. In some instances, a hemicoronal scalp flap provides the best access, especially for large tumors or ankylosis or when a temporalis flap is required.

- With the teeth in occlusion, an “L” osteotomy is designed from the remaining posterior ramus and angle (Figure 41-11). This will be the transport disk. The vertical limb parallels a vector that will bring the disk into the glenoid fossa. It is placed 12 to 15 mm from the posterior border to avoid injury to the inferior alveolar nerve. The osteotomy is outlined in the lateral cortex. It is not completed until after the distractor is attached.
- The leading edge of the disk is rounded to form a new condylar head (Figure 41-12).
- Internal, unidirectional distractors are used. Depending on the size and shape of the defect, an appropriate distractor is chosen. The position of the attachment plates and the direction the distractor opens must be determined.
- The vector of distraction is carefully aligned. The attachment plates of the device are trimmed and bent to passively fit the cortex of the mandible. A single screw is inserted in one plate. The vector is once again checked. If it is correct, holes are drilled for the remaining screws (but they are not yet inserted). At least three bicortical screws are used in each

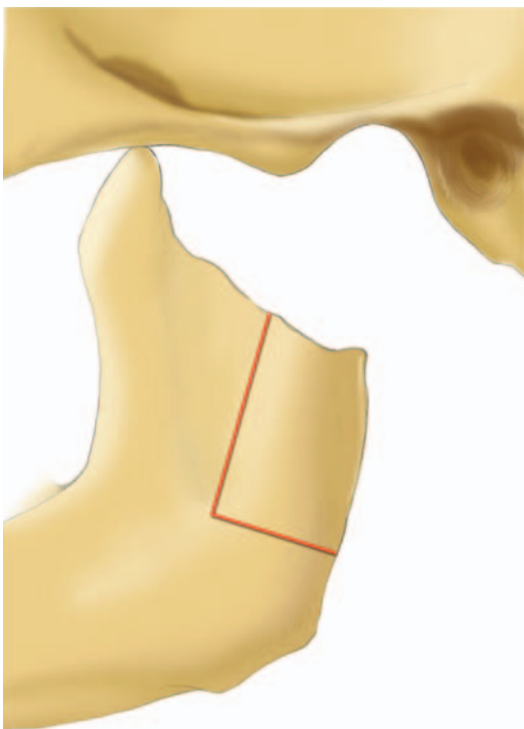


FIGURE 41-11 A transport disk is created by outlining an “L” osteotomy in the remaining posterior ramus and angle of the mandible. With the teeth in occlusion, the vertical limb of the “L” parallels a vector that will take the disk into the glenoid fossa. The osteotomy is not completed at this time.

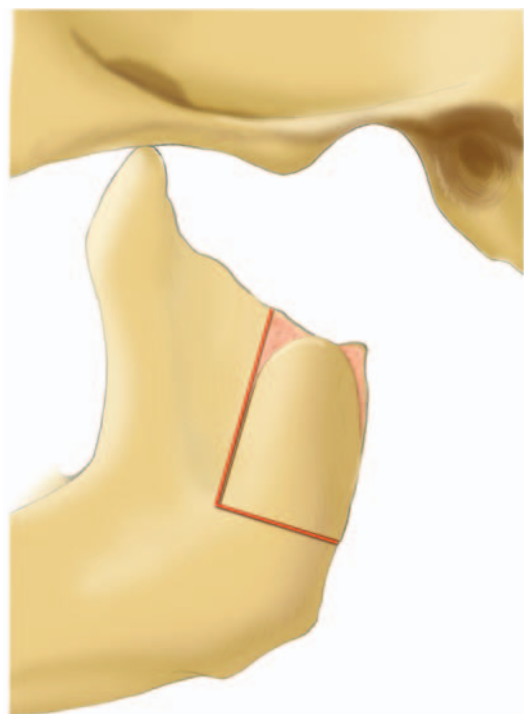


FIGURE 41-12 The leading edge of the disk is rounded. This will become the articular surface of the new condyle.

plate. If the vertical limb of the osteotomy is close to the inferior border, the inferior plate may be placed anteriorly. Monocortical screws are used if they overlie the inferior alveolar nerve.

- The distractor is removed, and a full-thickness osteotomy is almost completed. A small portion of the medial or posterior cortex is maintained so that the transport disk will not be displaced when the distractor is reattached. This is now done, using all of the screws. The osteotomy is then completed with a saw or by inserting a periosteal elevator and twisting (Figure 41-13). The distractor is opened several turns to be sure that the transport disk moves freely. It is closed once again.
- If pathology has been removed during the same procedure, there will be considerable dead space. This is usually obliterated with a graft of subcutaneous fat to deter heterotopic bone formation (Figure 41-14). In some cases, temporalis muscle is used as an interpositional flap.
- The activation rod is brought out through the submandibular incision or through a separate stab (Figure 41-15). All incisions are closed.

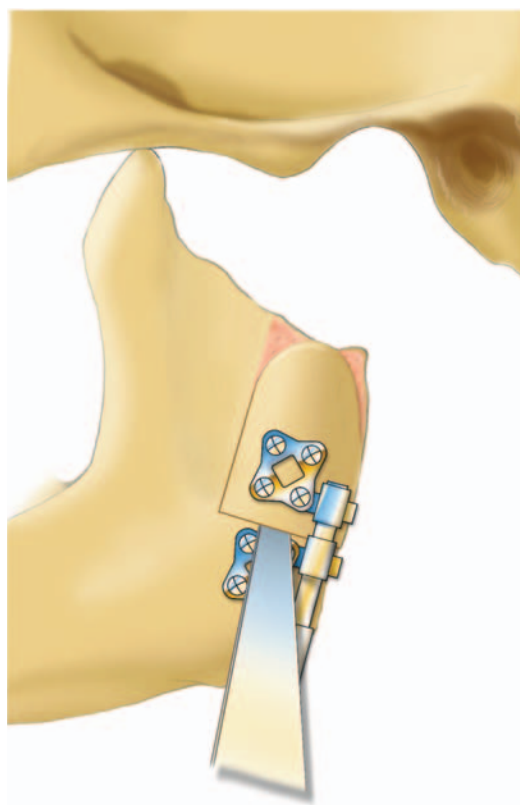


FIGURE 41-13 After an appropriate distractor has been attached, the osteotomy is completed. In this case, a periosteal elevator is placed in the osteotomy and twisted to free the transport disk.

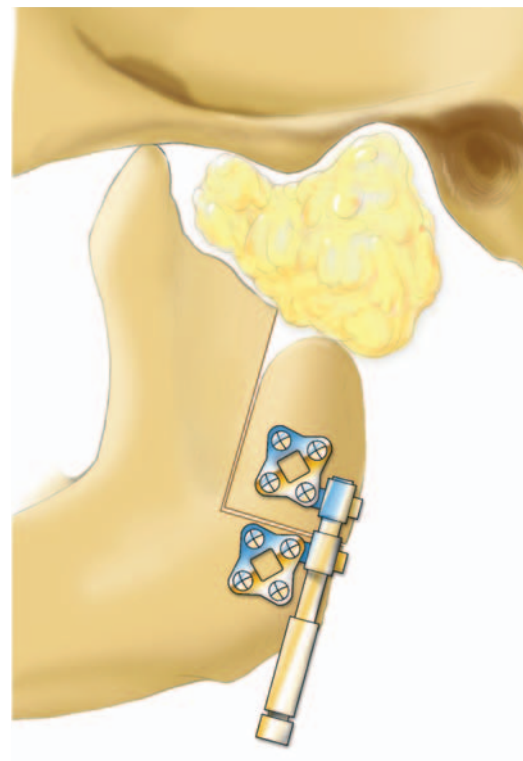


FIGURE 41-14 There will be dead space if a resection has been carried out during the same surgical procedure. It should be obliterated. Abdominal fat is generally used for this. In some cases, a temporalis flap is used.



FIGURE 41-15 Prior to wound closure, the activation rod is brought out through the skin.

Postoperative Care

- Normal wound care is used. The place where the activation rod penetrates the skin is covered with antibiotic ointment and a bandage. Perioperative antibiotics are usually given. There is no need for postoperative antibiotics.
- The patient is placed on a soft diet and on range of motion exercises.
- After a 7-day latency period, the distractor is activated 0.5 mm twice daily (Figure 41-16). The total distraction period can be estimated by the height of the RCU that is being reconstructed. It will vary somewhat owing to differences in the compressibility of the tissue interposed between the transport disk and the glenoid fossa.
- Distraction is stopped when the occlusion returns to normal. Some patients will “self-correct” their occlusion using muscular control. When the patient reports that the bite feels normal, it is important for the clinician to check this by retruding the mandible. Overcorrection has not proven necessary. At this point, callus in the distraction site has not yet ossified. The distractor is left in place to act as a fixation plate (Figure 41-17).
- In the case of patients with a preexisting malocclusion, distraction is carried to a predetermined position (a position from which orthodontics and/or orthognathic surgery will be carried out). This position is then maintained with a splint or by placing some composite on the occlusal surfaces of the teeth during consolidation.
- Ongoing, active range of motion exercises are important, especially for ankylosis patients (Figure 41-18).



FIGURE 41-16 On the seventh postoperative day, distraction is begun. The rate and rhythm are 0.5 mm twice daily.



FIGURE 41-17 Panoramic radiograph at the conclusion of distraction. Callus in the distraction gap has not yet ossified. The distractor is kept in place for fixation during consolidation. The distraction rod can be removed.



FIGURE 41-18 Range of motion exercises are continued long after distraction has been completed. This is of particular importance in ankylosis patients, such as the one pictured. Note that the distraction rod has been removed. The remainder of the distractor is visible as a bulge beneath the submandibular scar.

- When distraction has been completed, either the rod is removed or the skin is pushed back and the rod is cut short. The skin quickly closes so that there is little chance of infection (see Figure 41-18).
- The regenerate bone is allowed to consolidate for at least 3 months before the distractor is removed (Figure 41-19). The diet is slowly advanced to normal.
- The distractor is removed via the original submandibular incision. Devices that allow the distractor to be detached from one or both attachment plates (which remain in the bone) make this procedure much simpler. KLS Martin L.P. (Jacksonville, FL) makes a device that has two types of interchangeable, detachable plates and a detachable distraction rod.
- Orthognathic surgery, when indicated, is deferred for 6 months.



FIGURE 41-19 Panoramic radiograph following a 3-month period of consolidation. The callus has ossified, forming regenerate bone in the distraction gap. The distractor can now be removed.

Conclusions

This has proven to be a remarkably trouble-free procedure. Good regenerate bone has formed in all cases (Figure 41-20). The occlusion has remained stable, except in the case of one patient with severe rheumatoid arthritis who had ongoing degenerative changes in the reconstructed condyles. All patients have maintained a good range of motion, including lateral excursions, even ankylosis patients. It is recommended as an excellent alternative to autogenous bone grafting and prosthetic reconstruction.

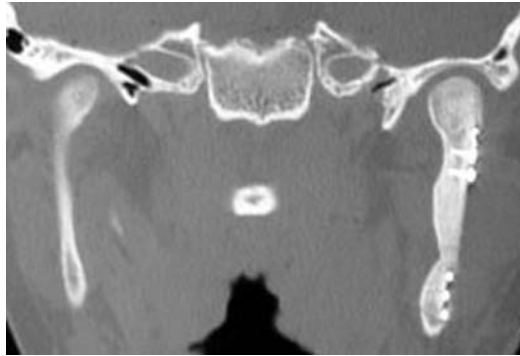


FIGURE 41-20 Coronal computed tomographic scan after 6 months. Note the remodeling of the new condylar head and of the regenerate bone.

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Distraction Osteogenesis in Oral and Maxillofacial Surgery Using Navigation Technology and Stereolithography

Kurt Schicho, Franz Watzinger, Arne Wagner, Astrid Reichwein, Gerhard Undt and Rolf Ewers

The combination of the surgeon's intraoperative view of the patient with additional computer-generated information (eg, preoperative planning) by means of overlay graphics is commonly known as augmented reality. Based on imaging modalities, mostly computed tomography (CT) and magnetic resonance imaging, computer-assisted navigation technology displays the positions and movements of surgical instruments relative to the patient and supports the surgeon's orientation. The use of this kind of technical setup is widespread and well established in several fields of medicine.¹ Therefore, we also call it the "first generation of navigation." A promising further development is the integration of three-dimensional stereolithographic (SL) skull models in a navigation workflow, enabling a new dimension of "haptic feeling" in the course of preoperative planning. SL models (Figure 42-1) are produced on the basis of CT scans of the patient. A laser beam cures liquid resin layer by layer, leading to a precise three-dimensional reproduction of the patient's anatomy. The optimum outcome of a simulated operation on the SL skull model can be exactly recorded with the navigation system and intraoperatively transferred to the patient by means of so-called point-to-point navigation.^{2,3} That is what we denominate the "second generation of navigation."

Technical Background

To support distraction osteogenesis, we applied a similar technical approach for the planning but were using surgical templates instead of point-to-point navigation. Navigation was used only to optimize preoperative planning, that is, to find out how many turns of the distractor are required for the desired longitudinal translation of the bone. The "link" between the patient and the simulated operation on the SL skull model is



FIGURE 42-1 Three-dimensional stereolithographic skull model of the patient. The pathologic deformity and asymmetry are clearly perceptible. The accuracy of such models (ie, the correspondence between the model and the patient's anatomy) has been proven in separate studies. A, Frontal view; B, lateral left view; C, lateral right view.



a simple template that connects the distractor rigidly and in a defined position to the bony structures of the patient respective to the corresponding parts of the SL skull model. Of course, an identical distractor must be used at the skull model and at the patient.

Patient

The patient was a 4-year-old female child. The diagnosis was right hemifacial microsomia, facial

asymmetry, and an open bite on the left side. Furthermore, the patient was suffering from dysplasia of the right auricle (see Figure 42-1).

Surgical Treatment

A three-dimensional SL model was manufactured according to the CT scan of the patient, and a distractor was attached to this model after osteotomy of the mandibular ramus (Figure 42-2). To allow for a precise definition of the position of the

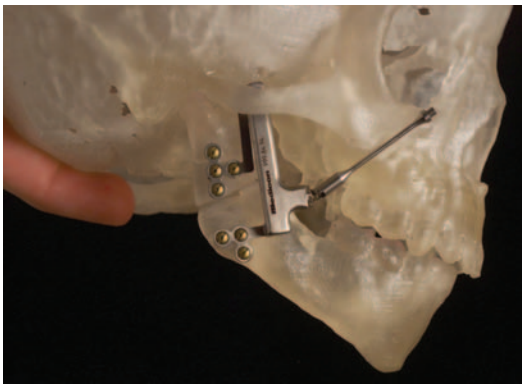


FIGURE 42-2 Distraction device in position during simulation surgery on the stereolithographic model.

distractor, we used a template; therefore, the distractor could be fixed to the patient at a position exactly corresponding to the position on the SL model in the course of planning.

The central part of planning is shown in Movies 42-1 and 42-2. By means of overlay graphics, planes and lines of symmetry were defined within the CT images on the navigation computer. Then two navigation sensors were attached to the SL skull: one at the mandible and the other at the maxilla. These sensors allowed us to follow the distraction process almost in real time. The distractor was turned until the desired symmetry was achieved. The number of turns required for this optimum result was the key information for the realization of this plan.

Intraoperative placement of the distractor (using the template) was finalized without any complications. The distractor was activated to 11.0 mm (1.0 mm per day), beginning from the fifth day after surgery. The retention phase was 3 months, and then the appliance was removed.

Clinical Outcome

Functional and esthetic results were very satisfying and are shown in Figures 42-3 (preoperative panoramic radiograph), 42-4 (distraction device in place), and 42-5 (2-year follow-up).

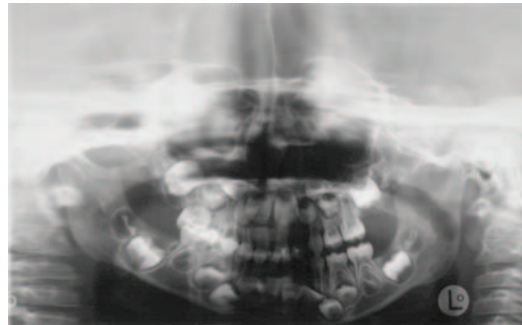


FIGURE 42-3 Preoperative panoramic radiograph. Asymmetric mandible with shortening of right mandibular ramus.

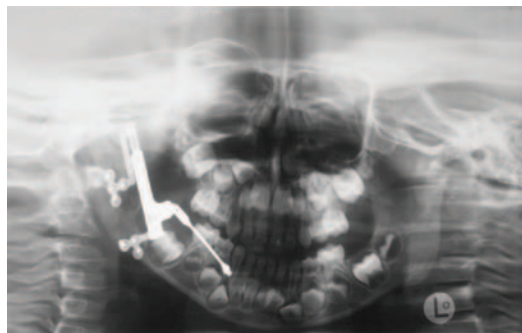


FIGURE 42-4 After 11.0 mm of distraction with the Medicon (Medicon, Tuttlingen, Germany) ramus distraction device in place.

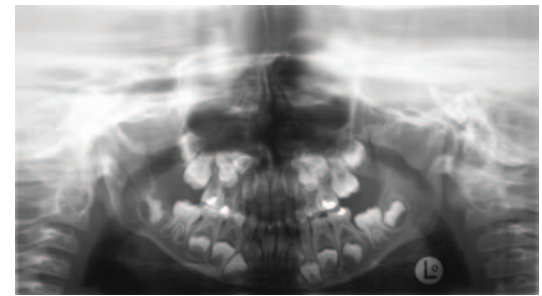


FIGURE 42-5 Two-year follow-up. A slight relapse of mandibular shortening is obvious.

Conclusion

The method presented in this chapter is a sophisticated approach to provide quantitative information for optimization of the distraction process. Nevertheless, the expenditure of time should be mentioned, and some experience with computer-assisted navigation is mandatory to derive a benefit from this technique.

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Arthroscopic Treatment of Functional Disorders of the Temporomandibular Joint with Computer-Assisted Navigation

Gerhard Undt, Kurt Schicho, Arne Wagner and Rolf Ewers

The application of computer-assisted navigation technology is well established in several fields of medicine.¹ The central principle is the application of so-called augmented reality environments that display actual positions of surgical instruments during the operation relative to two- and three-dimensional representations of the anatomic region based on imaging modalities (most frequently computed tomography [CT]), and they superimpose computer-generated overlay graphics to the real view of the surgeon on the patient, almost in real time.^{2,3} By means of special sensors that are attached to the patient's bone and to the instruments, the positions and relative movements are registered and the operation site is related to the computer model of the patient. This method allows for several applications in craniomaxillofacial and oral surgery. In this chapter, we outline how navigation can support the surgeon in the course of the treatment of temporomandibular joint (TMJ) disorders.

Technology

The main components are the computer (running the planning and navigation software), a tracking system (eg, based on infrared radiation), and the so-called "tools" of "sensors" that are attached to the patient and to the arthroscope to track the position and movement of the arthroscope relative to the patient's anatomy. Movies 43-1 to 43-3 and Figures 43-1 and 43-2 show the technical equipment as it is typically used for TMJ arthroscopies.¹⁻³

Patients

Patient 1

This patient was a 19-year-old female. Following a trauma to the mandible 2 years earlier, the

patient suffered from chronic pain and dysfunction in her left joint; conservative treatment for several months was not successful. The MRI scan showed displacement without reduction and osteoarthritis in the left TMJ. Severely limited translation of the condyle suggested the presence of intra-articular adhesions, which might have made arthroscopic surgery difficult if not impossible. A navigation splint was constructed (Figure 43-3), and CT was performed.

The patient's preoperative clinical status was as follows: maximum inter-incisal distance (IID) of 28 mm, protrusion of 8 mm with 2 mm deflection to the left side, and laterotrusion of 10 mm to the right and 11 mm to the left side. There was severe pain in the left joint on guided translation.

Operation: Navigation-guided puncture of the joint (Figure 43-4, Movie 43-4), arthroscopic lysis of lateral adhesions and anterior release⁴



FIGURE 43-1 Intraoperative setup of the navigation equipment (in this example by Artma, Vienna) in the operating room. The Digitizer (Polaris, Northern Digital Inc, Canada) (ie, an infrared light source sensor unit) is shown on the left. It is used for continuous tracking of the positions of the surgical instruments and of the patient by means of special navigation sensors with retroreflective marker spheres. The arthroscopic tower (light source, monitor, videorecorder) and a laser unit are also perceptible.

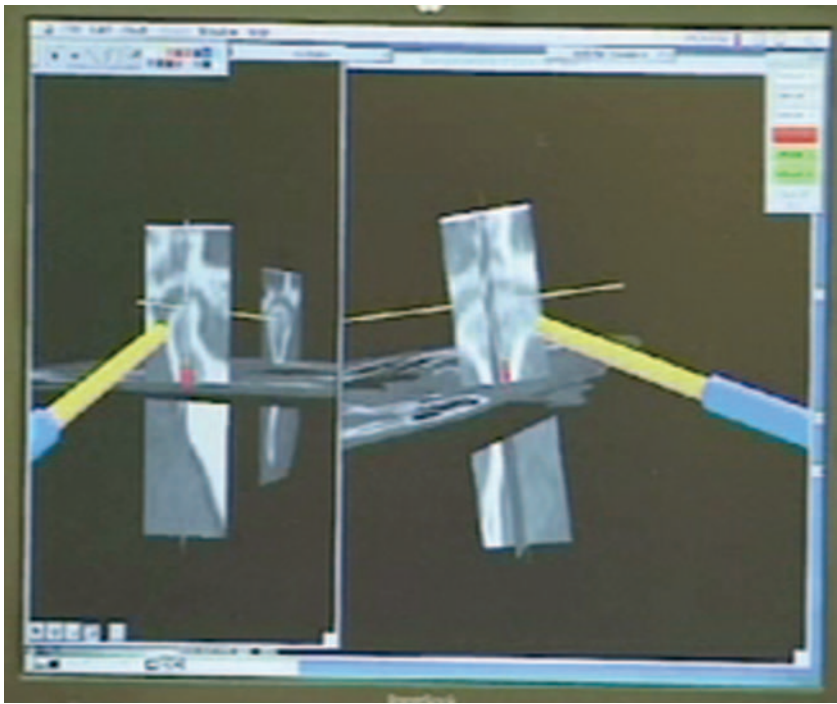


FIGURE 43-2 Intraoperative screen of the navigation software, supporting the surgeon with semi-three-dimensional representation of the operation site based on orthogonal cutting planes. The movement of the arthroscope can be observed relative to the patient's anatomy almost in real time.

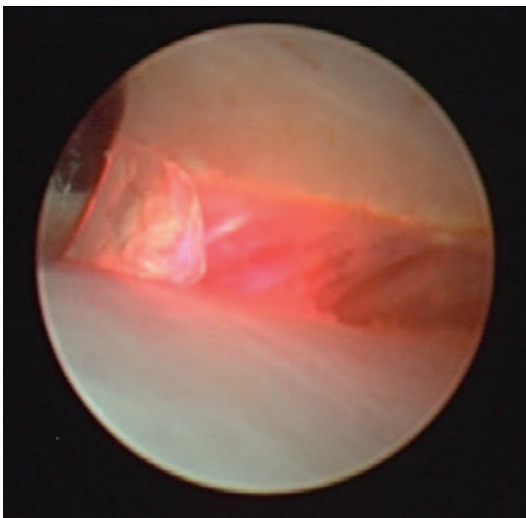
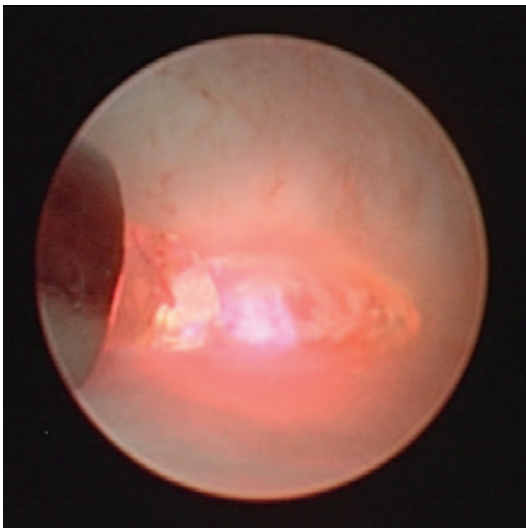
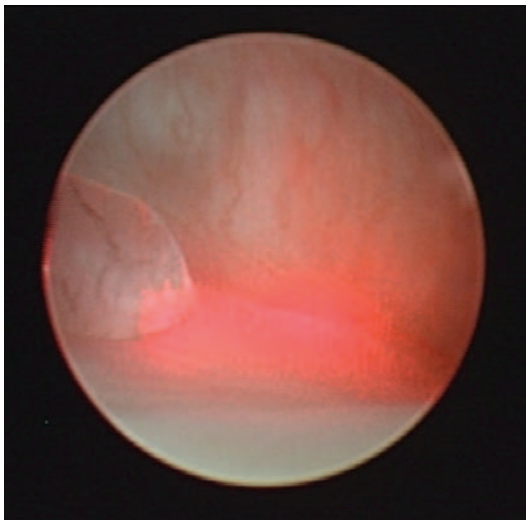


FIGURE 43-5 Anterior release⁴ of the articular disk with the holmium:yttrium-aluminum-garnet (YAG) laser. The high energetic light emitted by the infrared laser is invisible; the red light of a helium-neon laser serves as an aiming beam.



FIGURE 43-3 A navigation splint with fiducial markers (tiny steel spheres) is constructed and fits exactly to the upper jaw. While performing computed tomography of the patient wearing this splint, the positions of the fiducial markers are recorded in relation to the bony structures of the skull. These data are later used for intraoperative registration of the patient, that is, to define the relationship between the real patient and the corresponding computer model.²

of the articular disk with the holmium:yttrium-aluminum-garnet (YAG) laser (Figure 43-5, Movie 43-5), and scarification of the bilaminar zone with monopolar cautery (Figure 43-6, Movie 43-6).



FIGURE 43-4 Navigation-guided puncture of left temporomandibular joint. A sensor with three reflecting spheres is rigidly attached to the arthroscopic channel.

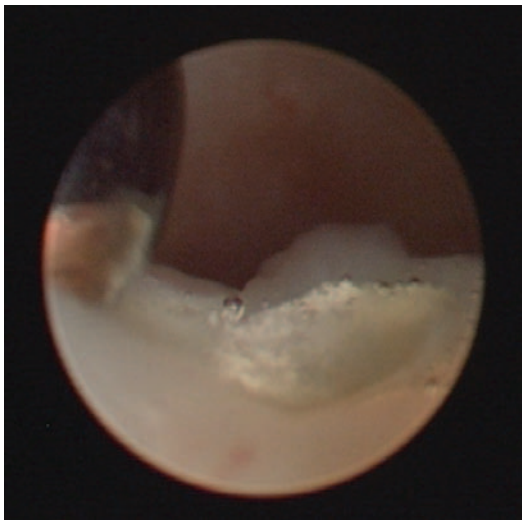


FIGURE 43-6 Deep thermocoagulation of the bilaminar zone with the aid of a blunt monopolar diathermy probe.

Figure 43-7 shows the position and mobility of the articular disk preoperatively and 2 years after surgery. Pseudodynamic magnetic resonance imaging of the joint 2 years following surgery shows good translation of the condyle and good disk position (Movie 43-7). An overlay of axiographic tracings preoperatively and 2 years after the arthroscopic surgery also demonstrates the improvement in function (Figure 43-8).

Five years after surgery, the patient was completely free of pain, with an IID of 52 mm without deflection, protrusion of 11 mm, and laterotrusion of 13 mm to the right and 12 mm to the left side.

Patient 2

This patient was a 63-year-old female. She presented with severe, extremely painful osteoarthritis in her left joint (Figure 43-9, Movie 43-8). As a first step, arthrocentesis and lavage of the joint were performed. Although 500 μ L of effusion fluid were removed from the joint space, no lasting relief of pain was obtained. Three months after arthrocentesis, an arthroscopic arthroplasty was planned. The fabrication of a navigation splint was impossible because of missing teeth in the upper jaw. Therefore, microscrews were positioned in the alveolar process to serve as fiducial markers for navigation.

The patient's preoperative clinical status was as follows: maximum IID of 38 mm, protrusion of 6 mm, laterotrusion of 7 $\times$ 10 mm, and extreme pain in the left joint on guided translation and compression.

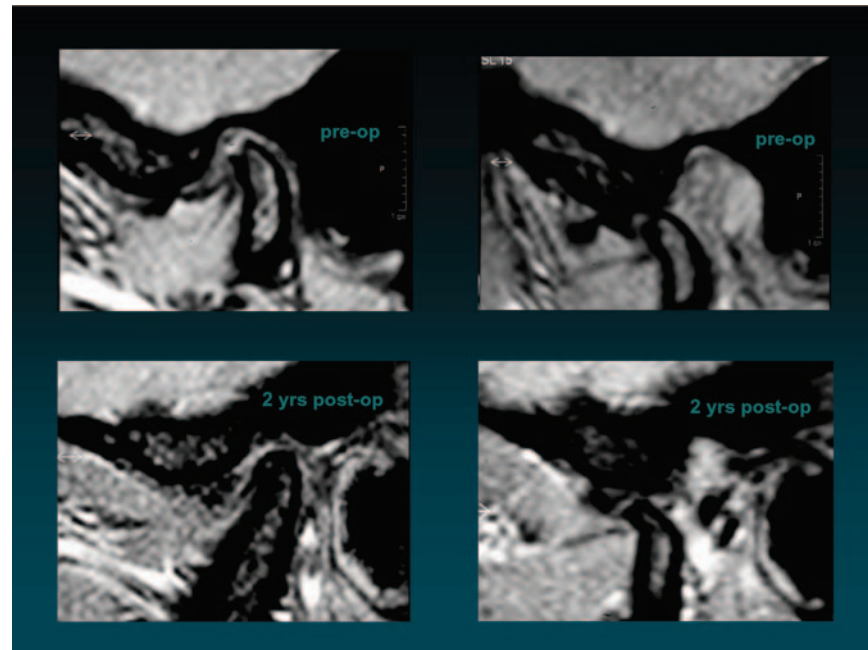


FIGURE 43-7 Magnetic resonance images of patient 1 representing the disk positions with a closed (*left*) and an open (*right*) mouth before (*upper row*) and 2 years after (*lower row*) navigation-aided arthroscopic temporomandibular joint surgery.

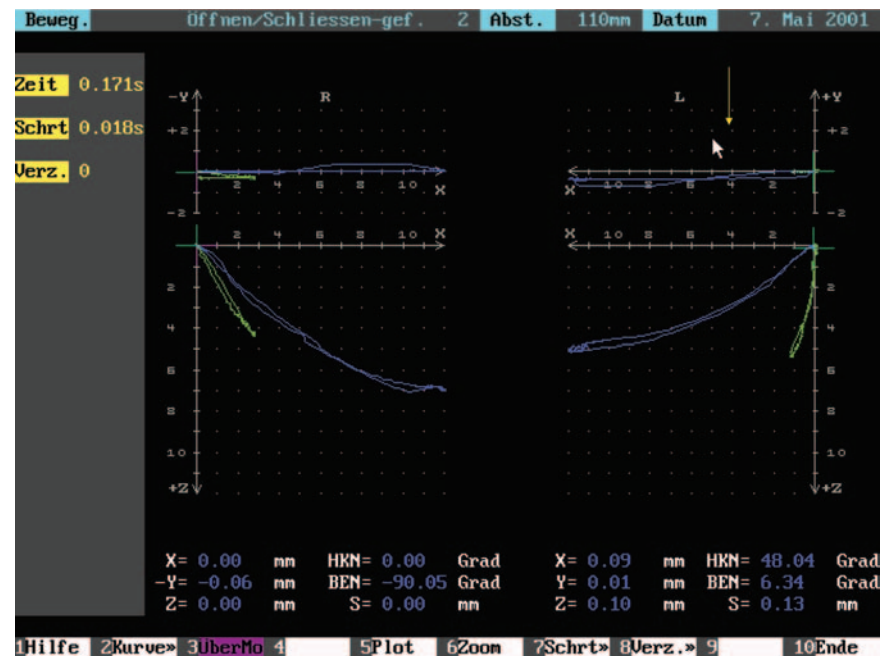


FIGURE 43-8 Axiographic tracings of patient 1; guided opening and closing movements. The *green* curves were recorded before and the *blue* curves 2 years after navigation-guided arthroscopic surgery.

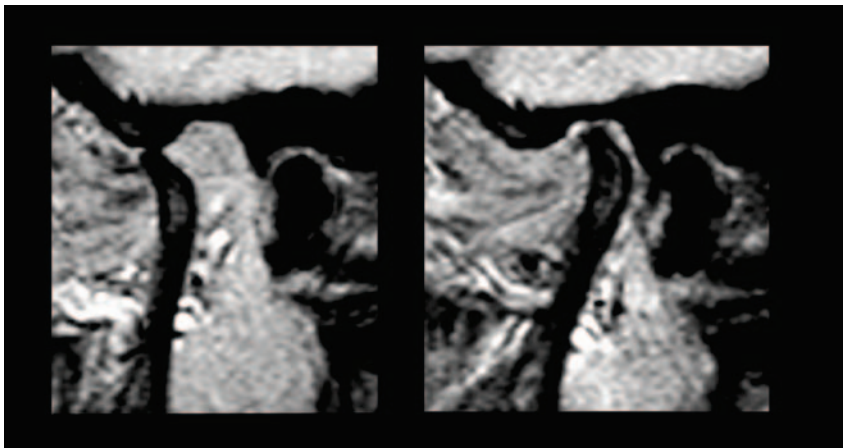


FIGURE 43-9 Pseudodynamic magnetic resonance image of the left temporomandibular joint of patient 2, open and closed mouth positions. The patient had severe osteoarthritis with large retrodiskal perforation.

Operation: Navigation-guided puncture of the left joint (Movie 43-9). Orientation within the joint was difficult owing to severe inflammatory and destructive changes of the joint surfaces (Movie 43-10, Figures 43-10 and 43-11). An arthroscopic arthroplasty with the holmium:YAG laser and an electromechanical shaver was performed (Movie 43-11, Figure 43-12).

Two years after surgery, the patient was free of pain in her left joint, and the maximum IID was 43 mm.

Patient 3

This patient was a 25-year-old female. She presented with bilateral recurrent mandibular dislocations, which had to be reduced in the hospital. A navigation splint was manufactured, and bilateral arthroscopic eminectomy was planned.

The patient’s preoperative clinical status was as follows: maximum IID of 47 mm, with 4 mm deviation to the right side during the excursive movement, and mild bilateral joint and muscular pain on maximum opening. There was no joint pain on guided translation and compression.

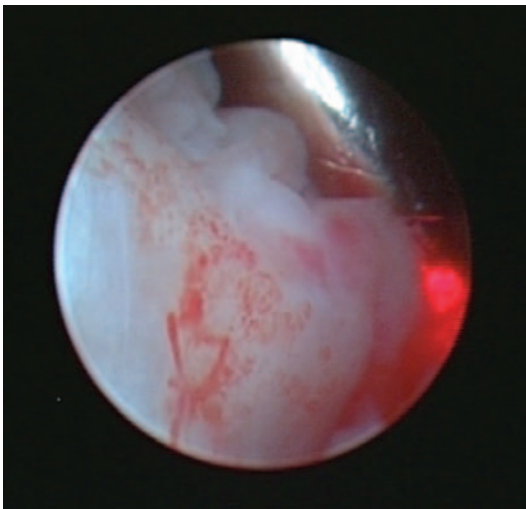


FIGURE 43-12 Polypectomy and synovectomy performed with the holmium:yttrium-aluminum-garnet laser (patient 2).

Bilateral arthroscopic eminectomy⁵ was performed with a 3 mm–diameter electromechanical shaver (Movie 43-12). The arthroscope and the shaver introduced through the second portal of entry were navigated (Figures 43-13 and 43-14). Navigation allowed for secure placement of the shaver in the vicinity of the skull base and the middle cranial fossa (Figure 43-15).⁶

Six months after surgery, the maximum IID was 46 mm without deflection or deviation, protrusion was 6 mm, and laterotrusion was 8 <> 9 mm. The patient was free of pain and did not suffer from any further mandibular dislocation.



FIGURE 43-10 Patient 2: severe inflammation of the synovia with formation of polyps.

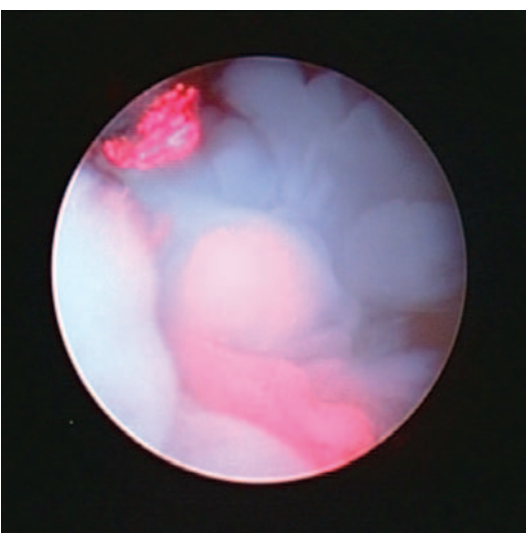


FIGURE 43-11 Polypous formations covering the condylar head.

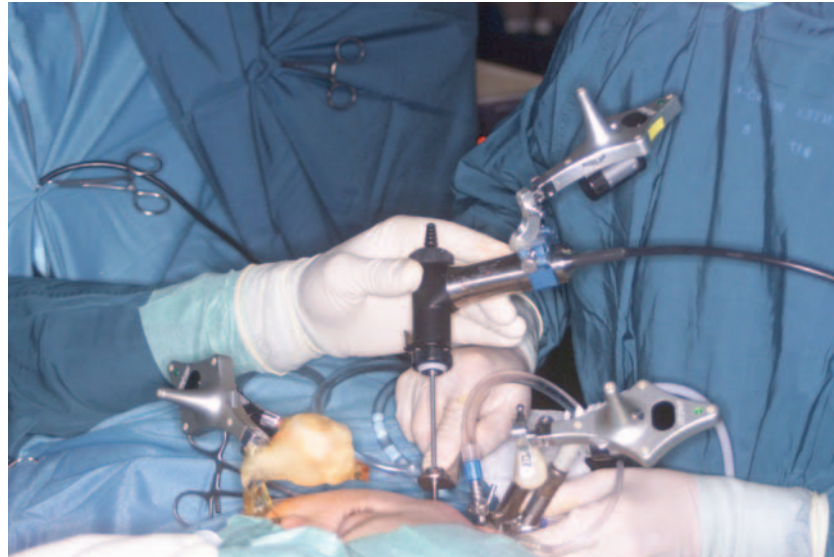


FIGURE 43-13 Navigation-guided arthroscopic eminectomy. An LED sensor is rigidly attached to the patient (*left*) to track his or her position continuously; similar sensors are fixed to the arthroscopic channel (*right*) and to the shaver introduced into the working channel (*middle*). The Stryker Navigation System (Stryker-Leibinger Inc., Freiburg, Germany) was used for this purpose.

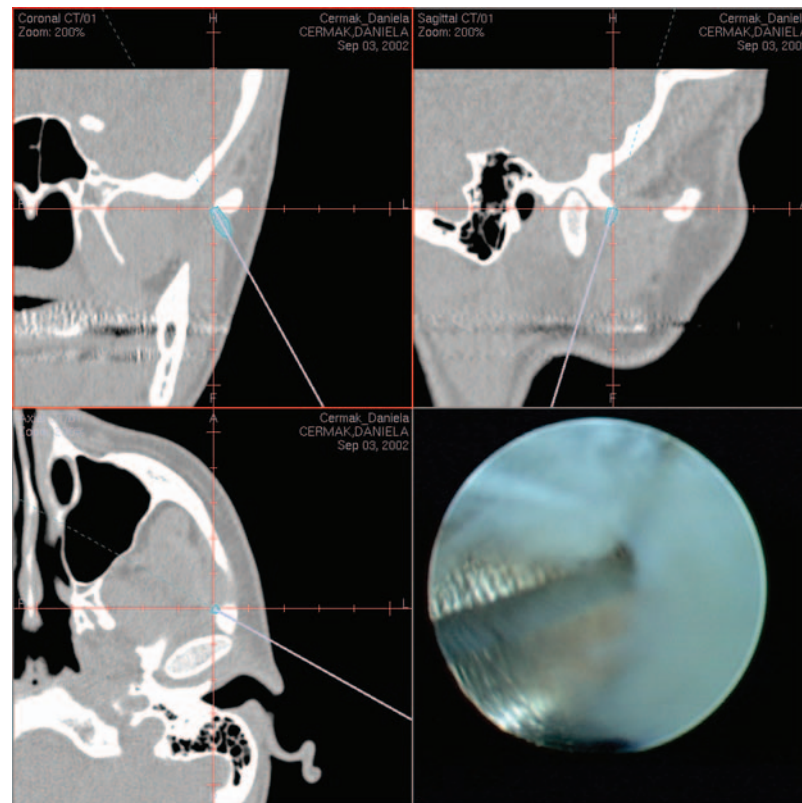


FIGURE 43-14 Three-dimensional projection and arthroscopic live image locating the position of the tip of the shaver in relation to the computed tomographic data set recorded preoperatively.

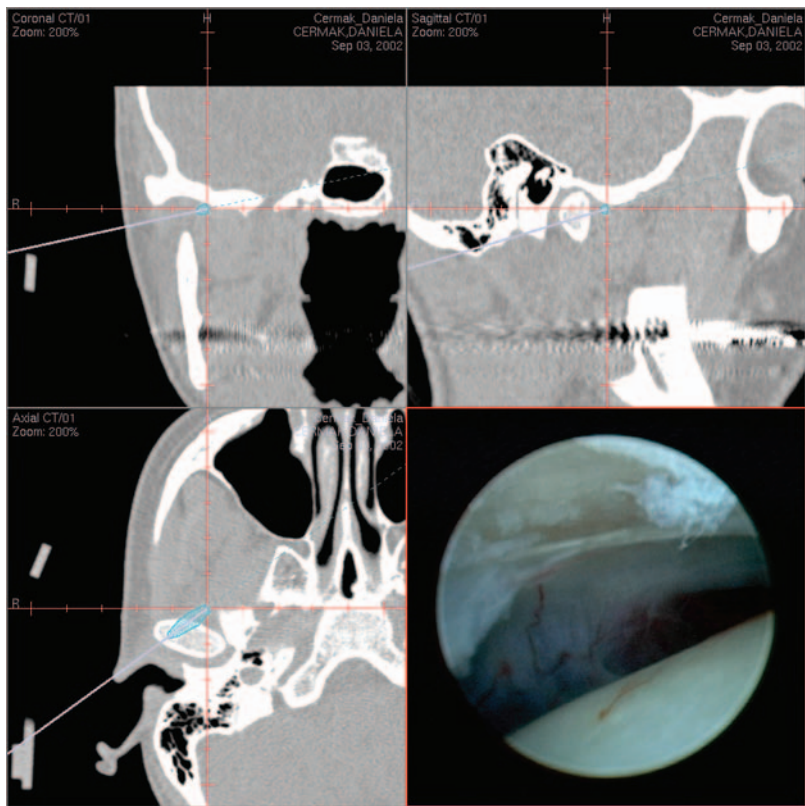


FIGURE 43-15 Three-dimensional projection and arthroscopic live image locating the tip of the arthroscope.

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Three-Dimensional Alveolar Distraction Osteogenesis

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New technologies have been developed in implant reconstructive surgery and prosthesis rehabilitation to maintain or improve the alveolar architecture with good hard and soft tissues quality and quantity around the fixtures. Alveolar ridge deficiencies have been treated by a variety of techniques: from bone grafting to soft tissue flaps, including autologous and nonautologous bone grafts (both cortical and cancellous), hydroxyapatite, collagen, and a number of different resorbable or nonresorbable membranes and meshes for guided tissue regeneration. However, regardless of the procedure or the material used, the surgical outcomes have been unpredictable and sometimes unsatisfactory, with various degrees of resorption and remodeling (Figure 44-1A and 44-1B).¹⁻³ This type of reconstruction forces the implant to be placed within fibrous scar tissue and poor vascularity, with the possibility of postsurgical retraction and periimplantitis (Figure 44-1C). Most of the scientific reports on traditional techniques lack meticulous evaluation, large data, and adequate long-term follow-up.

Today's dentistry standards in alveolar and implant treatment demand perfect smiles, with implant crowns emerging from ideal alveolar form and dimensions, with adequate papillae around them and a natural appearance; this requires a stable environment between the implant, the bone, and the surrounding soft tissues. There are eight rules to achieve gold-standard results: bone height, width, and anteroposterior (A-P) projection, hard and soft tissue quantity and quality, preserved buccal sulcus, adequate papillae, and gingival contour. In severe alveolar deficiencies secondary to traumatic, pathologic, or premature tooth loss, traditional surgery results are insufficient to assure ideal esthetics and functional reconstruction; in consequence, distraction osteogenesis has become a novel technique to treat these alveolar defects, creating new intramembranous bone and soft

tissues based on the biologic principle of tension and stress, thus obtaining an adequate volume of bone into which implants might be placed and where the histogenesis process favors normal perialveolar architecture (Figure 44-1D).^{4,5} If the dental implants are placed without previous adequate alveolar augmentation, then the surgeon will confront the need to reposition the bone and the implants, or to remove them and start the whole process of bone augmentation and implant placement.⁶

Since the reports made by Chin and Toth and others, to increase the alveolar region by distraction osteogenesis, along with the animal research by Block and colleagues, Ueda, and Oda and colleagues, this surgical concept has gained enormous popularity, basically because of its predictability and long-term stability satisfying the demands of both prosthodontists and patients.⁷⁻¹⁰

Alveolar ridge reconstruction by distraction osteogenesis may be indicated for the atrophic

alveolar process resulting from maxillofacial trauma, periodontal disease, and pathologic or congenital deformities. This technique may also be applied to dentulous segments for ankylosed teeth, infraocclusion, and particular open bites (Figure 44-2).

Distraction osteogenesis for alveolar reconstruction must be guided by the prosthodontist and should be reserved for situations where ideal implant placement and prosthetic rehabilitation will be enhanced by the treatment. It should not be chosen when a traditional Brånemark approach to the edentulous mandible or maxilla would produce predictable excellent functional and esthetic results. The use of alveolar distraction in the severe anterior mandible should not be indicated when there is insufficient bone, in order to prevent fractures of the basal bone at the lateral osteotomy site or unfavorable lingual orientation of the distracted segment; the placement of 3 to 5 long and wide implants between the mental nerves would allow immediate loading of dentures saving-time and long-term treatments.

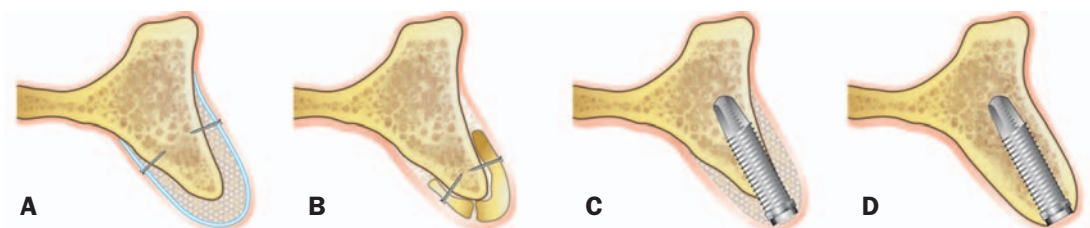


FIGURE 44-1 Traditional reconstructive alveolar surgery. A, Tissue-guided regeneration; (B) bone grafts have been unpredictable, with various degrees of resorption and remodeling. C, The implants were placed in fibrous scar tissue, with the possibility of postsurgical retraction and periimplant disease. D, Alveolar distraction produces hard and soft tissue enlargement with adequate height, width, and anteroposterior projection.



FIGURE 44-2 A, B, A 20-year-old male with a history of a motorcycle accident. He had multiple facial lacerations, partial avulsion of the anterior third of the tongue, and complete avulsion of all four mandibular incisors and right mandibular canine. The alveolar defect required a three-dimensional augmentation for dental implant placement.

for induction of distraction osteogenesis. If the vertical osteotomies are performed too close to the adjacent teeth, then the surgeon could incur the risk of exposing the root surface, with the consequent slower bone formation and damage to the periodontal tissues within this area.^{11,12}

The horizontal osteotomy should be positioned to construct a transport segment as large as possible without compromising the integrity of the remaining bone; the minimal bone height for the maxilla is 8 mm (4 mm basal and 4 mm distraction disk) and 15 mm for the mandible (10 mm of basal bone) to avoid undesired fractures. Distraction osteogenesis induces bone formation from the remaining osseous tissue, necessitating an adequate bone source.¹³ Osseous formation will be more predictable if the horizontal osteotomy spans the medullary space, as opposed to cortical bone only.

Once the osteotomies are finalized, the periosteal layer must be carefully closed, avoiding saliva and food contamination into the chamber and permitting full bone mineralization. The quality of the new callus depends on adequate closure of the distraction chamber, since this creates a biologic environment that favors creation and preservation of collagen type I fibers that would be stretched gradually for final bone formation. If chamber contamination occurs, then the collagen fibers would be disrupted and fibrous tissue or a weak callus formation is encountered, compromising subsequent implant osseointegration.

Biologic Considerations

Preservation of the periosteum and the endosteal blood supply is considered to be critical to optimizing the osteogenic potential of the host bone. The incision must be placed at the buccal sulcus rather than at the alveolar crest, and the periosteal layer minimally elevated. If the segment to be osteotomized is detached from the adjacent soft tissues, then it will act as a free bone graft, with a severe and unpredictable degree of resorption. Collateral blood supply provided by the lingual or palatal mucoperiosteum maintains the circulation that is necessary for distraction osteogenesis and histogenesis. Additionally, this approach allows soft tissue elongation at a site distant from the implant emergency, thus avoiding periodontal problems (Figure 44-3A–D).

The osteotomy must be carried out under abundant irrigation to maintain the temperature within biologic limits (<40.5°F), avoiding bone overheating. It must be bicortical, because a corticotomy may jeopardize the final result by transporting only the buccal cortex, shifting the bone segment lingually, or not permitting bone transport at all, requiring re-intervention.

Cancellous bone with marrow and the spongy components have the greatest osteogenic potential for healing. An adequate margin of bone contiguous with the adjacent teeth is necessary

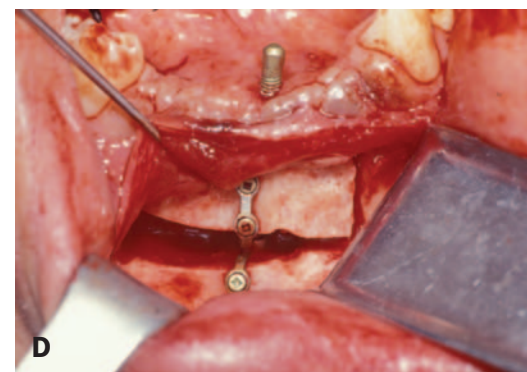
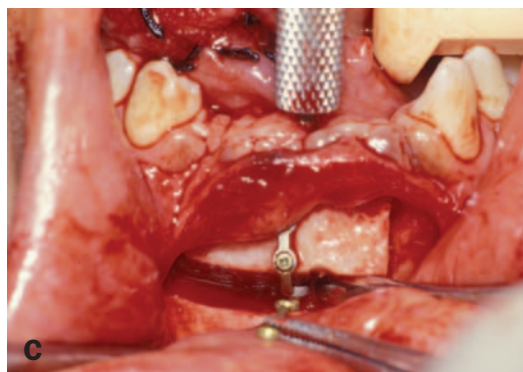
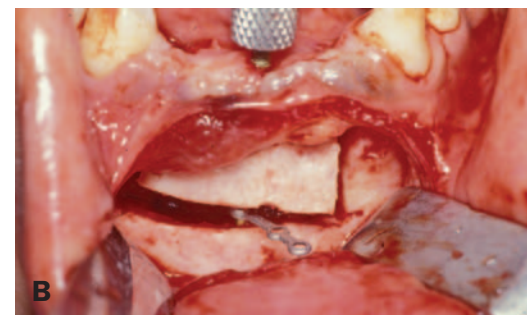


FIGURE 44-3 Surgical technique. A, An incision is made deep in the sulcus, with minimal periosteal detachment to preserve the vascularity of the transporting segment; the osteotomy is performed under abundant irrigation; and the distraction pin is inserted transmucosally in the center of the alveolar crest, taking the planned vector into consideration. B, C, D, The transport (B) and base (C) titanium plates are inserted at the end of the pin within the chamber and fixated with vestibular screws. The appliance is activated to verify its function (D).

The rate of distraction is decreased to 0.5 mm twice a day or even 0.5 mm a day in older or compromised patients, to avoid collagen type 1 fiber breakage or disruption in the distraction chamber.¹⁴ This is of particular importance in alveolar reconstruction, because it is more commonly performed in older patients and on small bony fragments. The segment will be transported until a 20 to 30% of overcorrection in a three-dimensional manner is obtained, to compensate for periosteal contraction and bone remodeling. The magnitude of overcorrection requirement is in relation to the size of the distraction movement; for example, a 3 mm correction for a 10 mm defect (30%) may be reasonable (Figure 44-4).

Historically, the bone was distracted in excess to allow the surgeon to reshape the alveolar form and to place implants in an ideal position, at the second surgical stage. However, the pressure exerted at the alveolar crest during the distraction process provokes reshaping on this area; therefore, the soft tissue management in implant dentistry today indicates no crestal incisions, in order to avoid papillae retraction and interdental black holes. The implants are placed transmuco-sally, and if any augmentation is needed, the sulcular approach is used, to augment either with bone or connective tissue grafts.

The consolidation period for complete mineralization extends for 10 to 12 months, with minimal changes after 3 months. The insertion of dental implants is performed 3 or 4 months

after the first surgical stage. The distraction mineralization takes place simultaneously with the osseointegration process, so the implants need to be long enough to reach and penetrate the distracted disk, the chamber, and the basal bone, in order to achieve bone stability during the final period (Figure 44-5).¹⁵

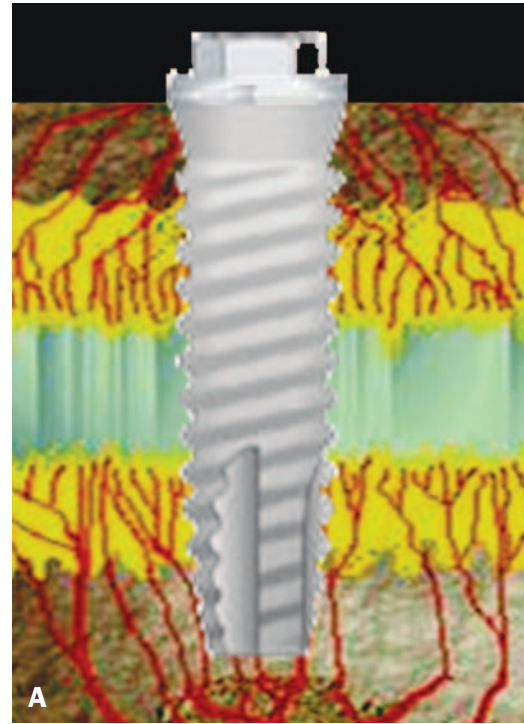


FIGURE 44-5 A and B, Implant placement after 14 weeks. The fixture length is chosen according to the total length, which includes the transported bone, the distraction chamber, and the basal bone.



FIGURE 44-4 Intraoral lateral and occlusal views. Observe the original defect (A, C), and the soft and hard tissue enlargement after alveolar distraction (B, D).

suture stitch is placed around the implants along with periodontal acrylic to enhance the biologic closure around the implants. The implants are placed in one stage, but are not loaded until osseointegration and chamber mineralization are achieved. Different prosthetic designs can be used for temporary teeth during the healing process

Technical Considerations and Surgical Planning

Before alveolar reconstruction is considered, a complete evaluation of the patient is mandatory, including the medical history, dental history, previous surgeries in the alveolar ridge, origin of the deficiency, clinical evaluation of the defect, dental occlusion, radiographic evaluation, and the patient's compliance with treatment (Figure 44-6).

With regards to the evaluation of the alveolar defect, it must be assessed in a three-dimensional manner (Figure 44-7). Dental impressions are taken, and the models are mounted in a semi-adjustable articulator in centric relation. A surgical prediction wax-up of the alveolar area to be augmented is made with pink wax, with a 20 to 30% of overcorrection in the vertical and

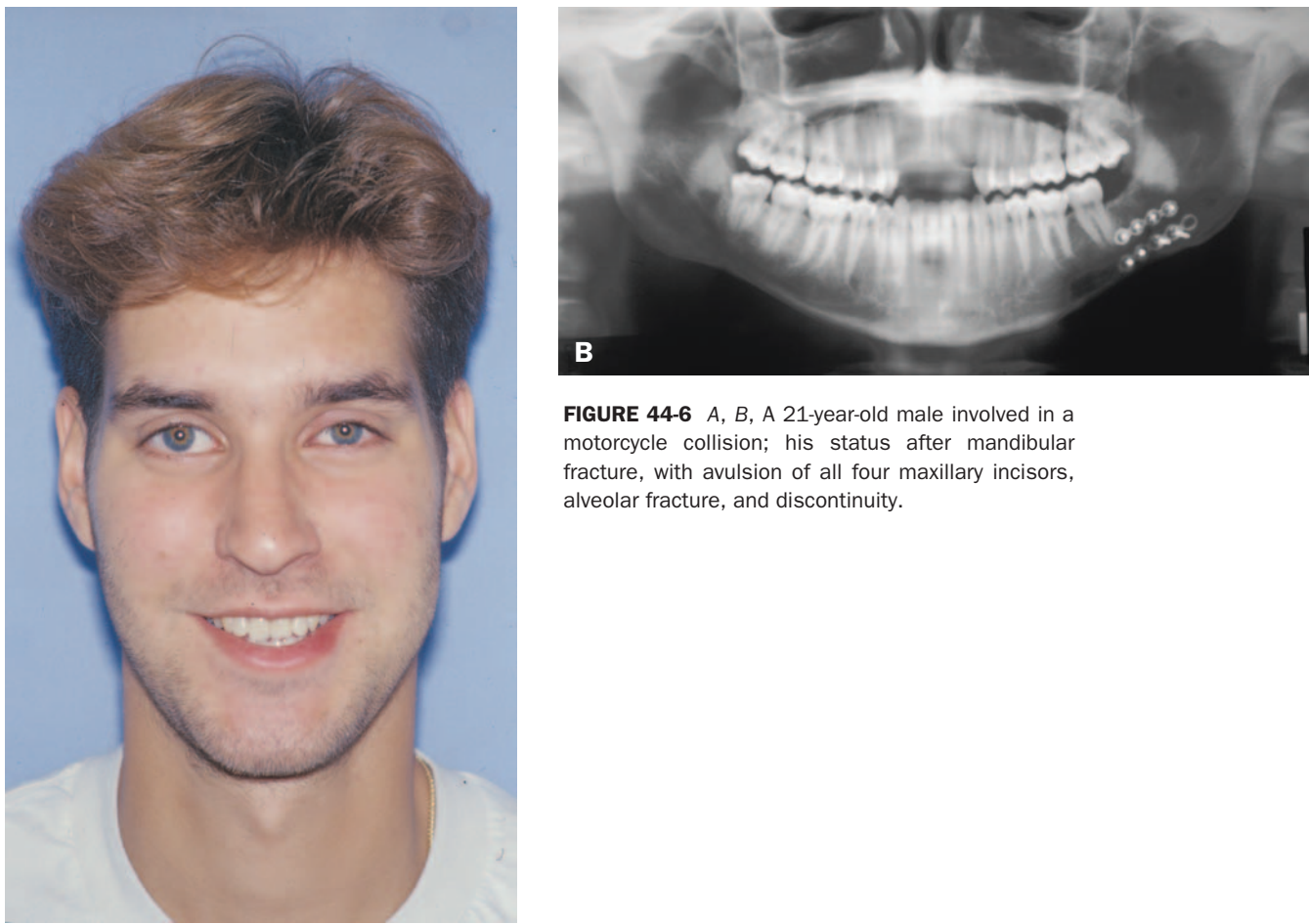


FIGURE 44-6 A, B, A 21-year-old male involved in a motorcycle collision; his status after mandibular fracture, with avulsion of all four maxillary incisors, alveolar fracture, and discontinuity.

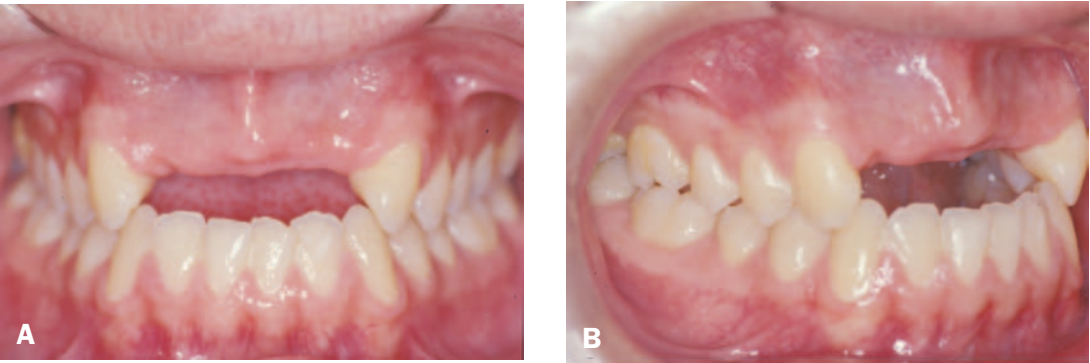


FIGURE 44-7 A, B, Alveolar defect in the anterior maxilla; frontal and lateral intraoral views showing severe anteroposterior atrophy.

A-P planes, even though it might seem inadequate for the prosthetic space. The level of the horizontal osteotomy is marked on the dental cast, taking into consideration the radiographic height of the remaining bone; this level will dictate the width of the transport segment and the final thickness of

the alveolar reconstruction. With these goals in mind, the distraction vector is assessed and the distance from the horizontal osteotomy to the overcorrected wax-up is measured to select the adequate length of the distractor rod; if it is too long, then it will interfere with occlusion,

resulting in inadequate motion of the distraction segment, and fibrous tissue formation at the chamber; if it is too short, then an insufficient reconstruction will be obtained, with poor final esthetic results. This correct presurgery work-up must not be underestimated, in order to avoid the meager outcomes shown in several publications on alveolar reconstruction by distraction osteogenesis.

As mentioned above, the distraction vector is very important, especially in the anterior maxilla where esthetics are crucial. The atrophy pattern is vertical as well as A-P in the anterior segments. Therefore, a cephalometric prediction tracing for A-P projection and vertical overcorrection helps, together with the presurgical wax-up on the vector assessment. In the anterior maxilla, an angle of 30° to 45° from the horizontal is usually adequate, using the clinical Frankfort horizontal plane (porion–orbitale) as a reference (Figure 44-8).

For the anterior mandible, the angle formed between the long axis of the mandibular incisors and the mandibular plane (1 MPA 95°) is used for the vector planning (Figure 44-9).

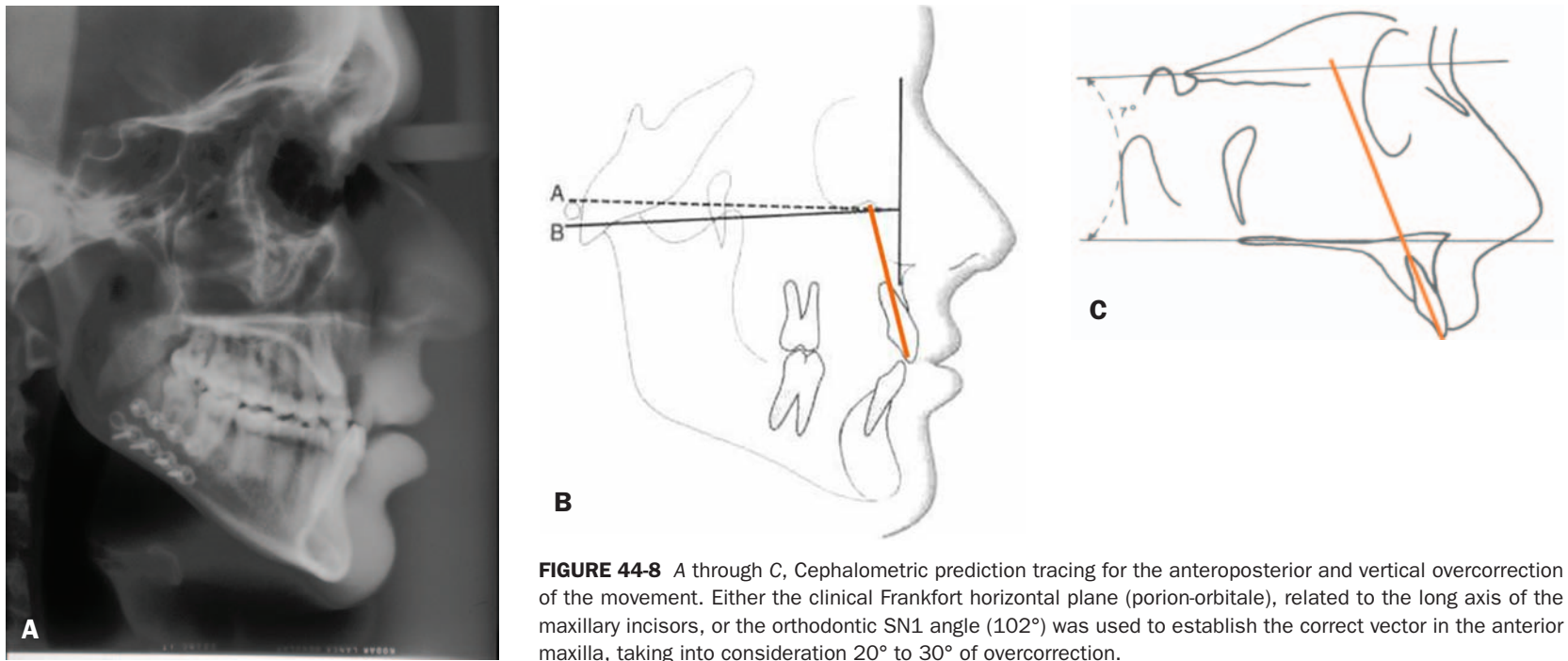


FIGURE 44-8 A through C, Cephalometric prediction tracing for the anteroposterior and vertical overcorrection of the movement. Either the clinical Frankfort horizontal plane (porion-orbitale), related to the long axis of the maxillary incisors, or the orthodontic SN1 angle (102°) was used to establish the correct vector in the anterior maxilla, taking into consideration 20° to 30° of overcorrection.

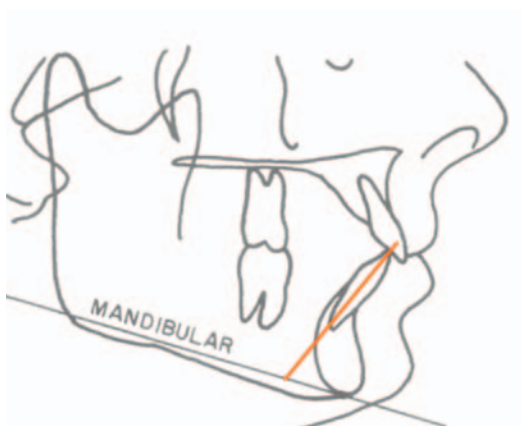


FIGURE 44-9 The mandibular plane to central lower incisor angle is used to plan the vector of the anterior mandible (1MPA: 95°).

The prosthodontist makes the dental wax-up in the ideal position over the alveolar wax-up; at this time, the teeth may look smaller in the vertical dimension because of the alveolar overcorrected wax-up. Based on this prosthodontist work-up, an occlusal splint is made to serve as a surgical guide for the desired vector angulation during the drilling process. A perforation is made on the splint to reproduce the ideal rod inclination at the time of surgery; it is very important to mention that this perforation or notch must be near the tooth cervical aspect, on the buccal side rather than at the incisal edge, to increase the projection of the alveolar process as well as the prosthodontic possibilities to achieve ideal emerging crowns and gingival contour (Figure 44-10).

After surgery, the same splint could be filled up with acrylic to simulate the missing teeth, and could be used as the provisional prosthesis during the distraction process, grinding the cervical aspect of the splint to allow the segment movement toward the planned position during activation (Figure 44-11).

There is a minimum amount of bone extension required for alveolar reconstruction by distraction osteogenesis. The size of the distraction segment must be a minimum of a 2-tooth area, or 8 mm. The vertical osteotomy gaps (1 mm each one) and the rod placement, which is 2 mm in diameter, eliminate the possibility for very small fragments. Special attention should be given to small segments, as they are easily stripped from the soft tissues and transform into free grafts,

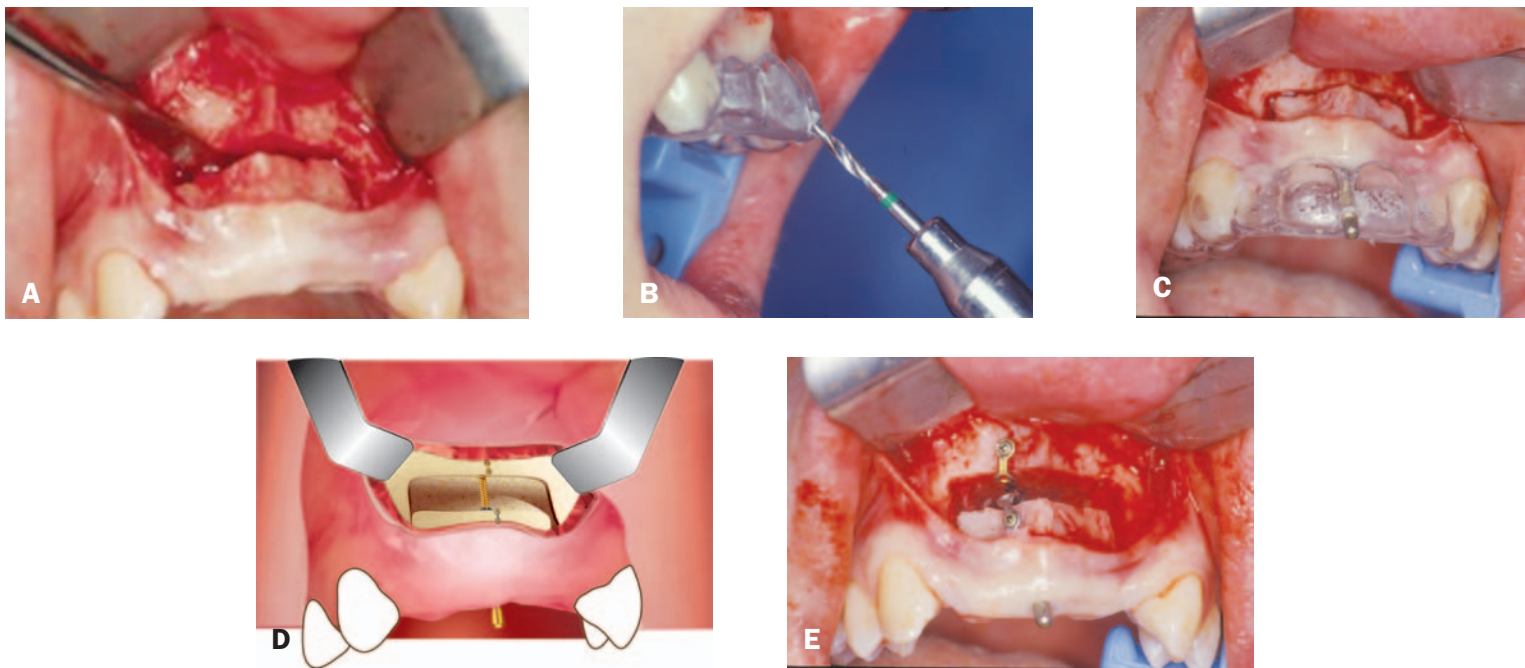


FIGURE 44-10 Surgical technique. A, The sectioning was gently finalized with a fine spatula or curved osteotome, producing an approximately 4 mm separation at the base to allow the placement of the intraosseous appliance. B, C, The use of a surgical guiding splint is essential for keeping the desired vestibular angulation during the drilling process, based on the prosthodontic work-up. D, E, The internal distraction device in place. Observe the transport and base titanium plates with the distraction rod.



FIGURE 44-11 A, B, Pre- and immediately post-intraoral occlusal views. The surgical splint was used provisionally during the distraction process. C, D, The implants were placed 3 months after alveolar distraction. The fixed prosthesis in place, after 4 years of follow-up.

limiting the distraction process. Space distribution by orthodontic means must be performed prior to the surgery, to achieve enough interdental space or to correct radicular axial inclinations that would interfere with the vertical bony cuts (Figure 44-12).

The tendency to perform the osteotomy parallel to the roots of the adjacent teeth is inconvenient for the planned movement; the final segment needs to be extrusive from the alveolar base, and the vertical cuts must be divergent toward the movement direction, avoiding an inverse pyramid design that would interfere with the distraction movement. The osteotomies are performed at least 1 mm away from adjacent tooth, thereby conserving the periradicular bone to prevent injuries to the teeth, fibrous tissue formation with no osteogenic capacity, and future periodontal and esthetic problems (Figure 44-13).

In larger segments, additional principles may apply. Major movements of bigger segments (4-tooth area or more) require the use of two rods, because there is a different vertical gain requirement along the defect and it is easier to control the final repositioning (Figure 44-14).¹⁶ Additionally, when using only one distractor in a large segment, there is a risk of uncontrolled shifting of the transport disk (due to different adjacent soft tissue flexibility) that will facilitate the movement in one edge and impair it in the other one (Figure 44-15).



FIGURE 44-12 A, B, Panoramic and lateral cephalometric postoperative radiographs showing the vertical position and anteroposterior projection of the distraction rod after activation.



FIGURE 44-13 A, Alveolar defect in the anterior maxilla, secondary to trauma. B, Observe the vertical and anteroposterior overcorrection, healthy attached gingival tissue, and bone width and height obtained. C, Prosthetic rehabilitation. Four years after treatment.

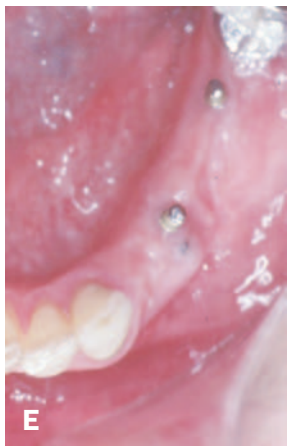
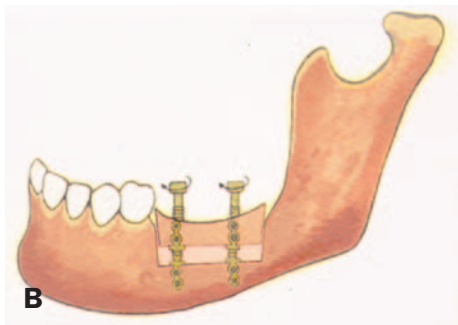


FIGURE 44-14 A, D, Posterior mandibular atrophy. B, C, E, F, Two intraosseous distractors in long segment deficiencies, to avoid shifting of the transport disk. G, The consolidation period is extended to a minimum of 6 months in posterior mandibular cases, before the implants are placed.



FIGURE 44-15 Radiographic sequence: pre (A), immediately post (B), and with the fixtures in place (C).

A different situation occurs when only one side of the segment needs to be augmented; here, a 3-hole plate is fixated on the nondeficient side, permitting rotation of the segment while the rod on the deficient site is activated, distracting just the required side.

The distraction vector assessment is important, as well as maintenance during distraction and consolidation. When reconstructing the anterior maxilla by distraction, both the hard keratinized soft tissue from the palate and the soft mucosa in the buccal side pull the distraction vector posteriorly, resulting in time planning loss and deficiencies in A-P projection of the alveolus. Several techniques for vector control have been developed (Figure 44-16). One option is the fixation of the base plate of the endosseous distractor over the palate, to obtain a more vestibular inclination of the rod's vector. In this case, the only modification on the surgical technique is to make a 2 mm incision on the palatal mucosa at the level of the horizontal osteotomy, to pass one hole of the base plate into the chamber, using 3.0 silk to pass the plate through, and to receive the rod and fixate the other two holes over the palate with transmucosal screws. The second option is to use a vestibular wire around a screw placed at the anterior nasal spine and the distractor's rod, to improve and maintain the vector. Wires to the teeth are also used to correct the vector laterally.¹⁶

The possibility to change the distraction vector after surgery is of extreme importance (Figure 44-17). The placement of the distractor is done very carefully, with the understanding that the vector of distraction is dictated by the direction of the device; however, there were clinical situations where the hard, keratinized tissue on the palatal side and the very loose and flexible mucosa on the buccal side caused the distractor to lean during activation and the segment to move inadequately. In such cases, a hinge-joint mechanism was used to help recover the adequate pathway; a heavy interdental wire or a secondary bone screw was used to force the rod into the desired inclination (Figure 44-18).

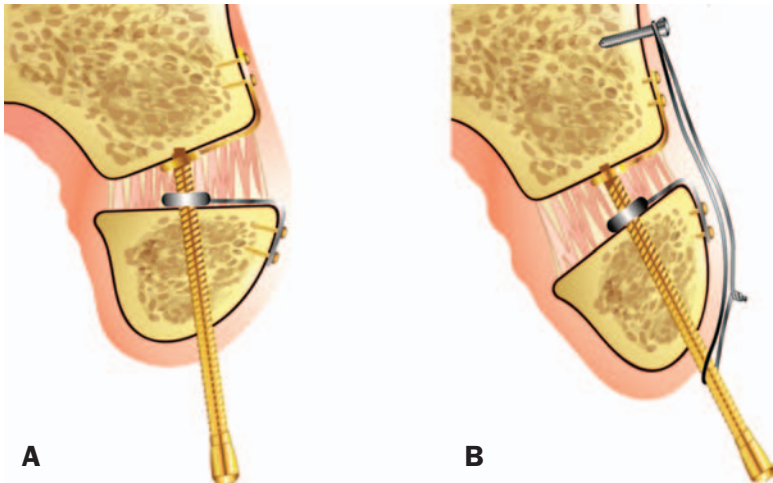


FIGURE 44-16 A, The distractor is placed with the proper vector inclination. The palatal mucosa is keratinized and nonstretchable, whereas the buccal mucosa is soft and flexible, bending the segment palatally. B, A buccal vertical wire fixed to the anterior nasal spine area can be used to change the distraction vector after surgery and maintain the segment position throughout the healing phases of distraction.

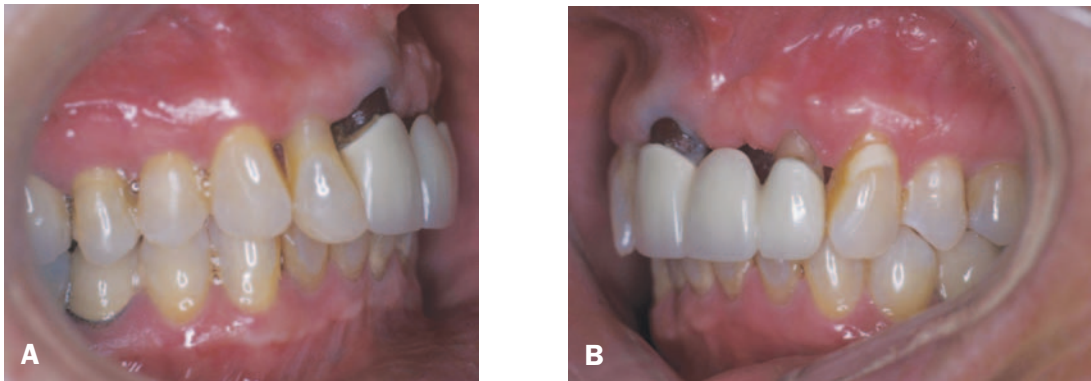


FIGURE 44-17 A, B, A 50-year-old female patient with an important esthetic compromise, in the anterior maxillary area, and periodontal disease.

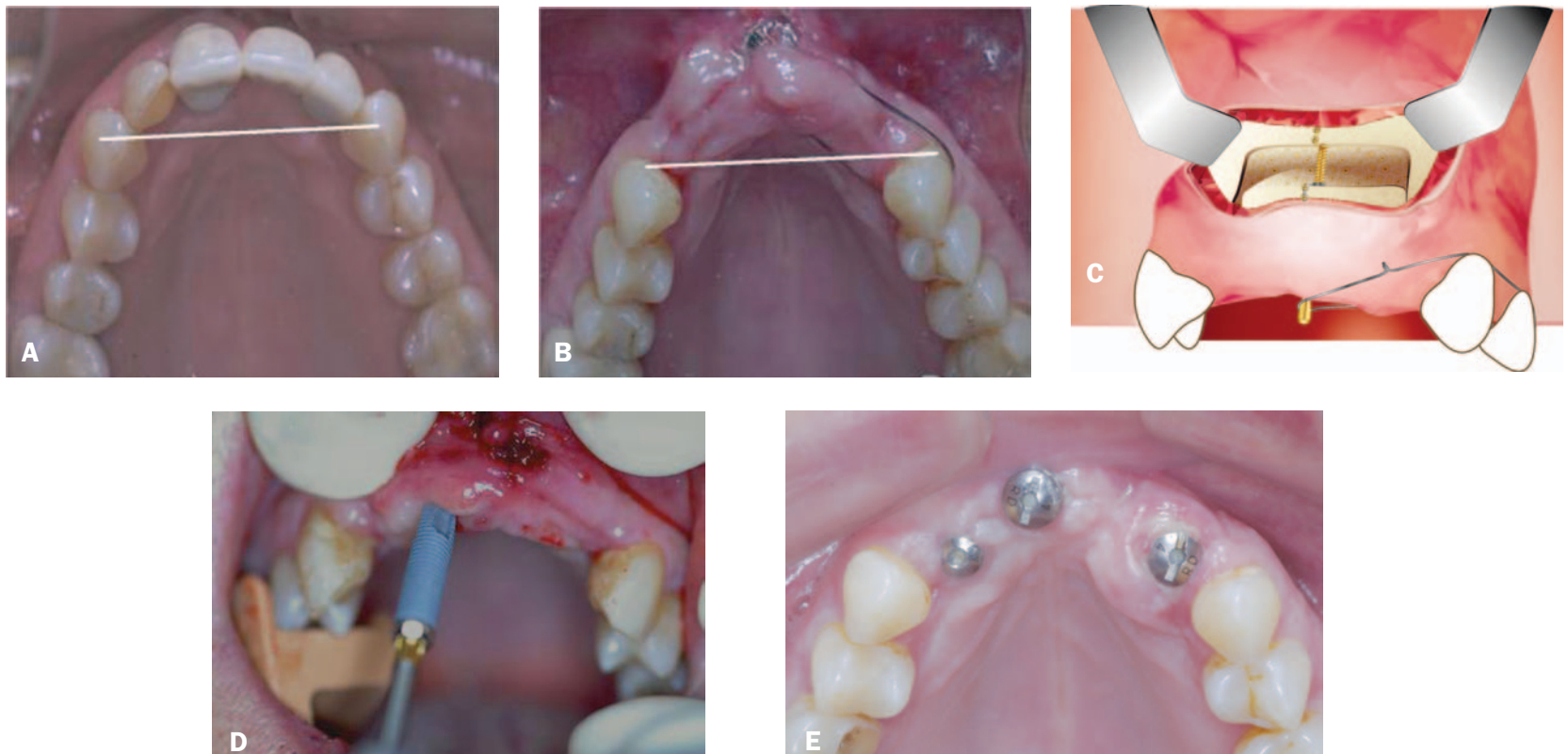


FIGURE 44-18 A, Intraoral occlusal preoperative view. B, Immediately postoperative occlusal view. All maxillary incisors were removed. Note the soft and hard tissue enlargement after alveolar reconstruction by distraction osteogenesis, preserving the intercanine distance. C, A wire around the first left maxillary canine was used to control the vector laterally during the activation and consolidation phases. D, Implants were placed in a flapless fashion through the mucosa, avoiding the subsequent vertical resorption and papilla compromise. E, Six months postoperative occlusal view, showing healthy attached gingival tissue around the fixtures.

We must understand and follow the biologic principles and apply the mechanical devices to develop the new tissues, maintaining the possibility to change the vector of distraction after surgery. This explains why the endosseous distractor with additional screws and wires were used in the lack of better distraction devices (Figure 44-19).

Recently, we have developed a vector control plate, which is a very versatile 8-hole “Y”-shaped plate that allows us to achieve the correct vector at surgery and has sufficient strength to maintain it until implants are placed. The plate is fixed to the palate with 4 or 6 screws, transmucosally, and it can be replaced in the event of undesired bone movement (Figure 44-20).¹⁷

The micromotion associated with the use of some distractors in our previous studies suggests that absolute rigidity is not necessary for mandibular widening and lengthening. Indeed, the micromotion provided by the flexible distractor arms is more likely a stimulus to osteogenesis.¹⁸ However, in alveolar distraction, where small segments are manipulated, this motion is not minor, as it would be in larger bone segments and may induce fibrous tissue formation instead of bone callus. The vector-control rigid plate is also used to improve the distractor stability, thereby enhancing bone healing.



FIGURE 44-19 Before (A, C) and after (B, D) anterior maxillary alveolar distraction and prosthetic rehabilitation.

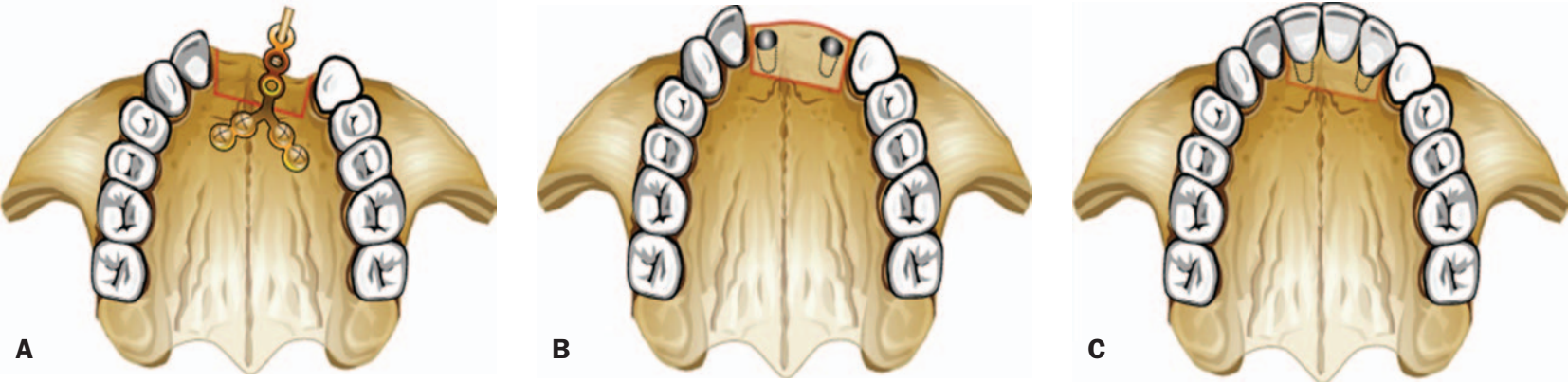


FIGURE 44-20 A, A vector controller plate over the palate fixated transmucosally is used to avoid positional changes throughout the activation and consolidation phases of distraction. B, The implants are strategically placed to maintain adequate separation. C, The final prosthetic bridgework.

Types of Devices: Advantages and Disadvantages.

Considering the biologic principles and the goals of alveolar reconstruction to satisfy today’s standards and needs of ideal smiles in prosthetic rehabilitation, there are numerous types of intra-oral distractor appliances available, but basically, they can be grouped into categories: the bone supported either extraosseously or intraosseously and the hybrid distractors. All of these devices require a second stage surgery for implant placement. Among the intraosseous devices, the implant distractor was developed to overcome the need for a second surgery to place the implants, or the remaining implants would be fixed in a second stage, maintaining the implant distractor to be part of the dental rehabilitation.

There are essentially three approaches to lengthening the alveolar area:

1. The extraosseous distractor or buccal device^{19,20}: In this approach, an incision is made in the sulcus to expose the basal bone and the alveolus, the osteotomy is performed, and the device is screwed to fixate both bone surfaces. Once the segment movement is visualized, the soft tissues are approximated and sutured (Figure 44-21).
2. The intraosseous device.
There are two sub-types of intraosseous devices: 1) the implant distractor and 2) the internal replaceable device.
The implant distractor requires a crestal incision, the bone could be trimmed down to proper width, an osteotomy is designed according to the individual need, and then the wound is carefully closed (Figure 44-22).^{21,22} After the latency and activation period and after the segment has arrived to

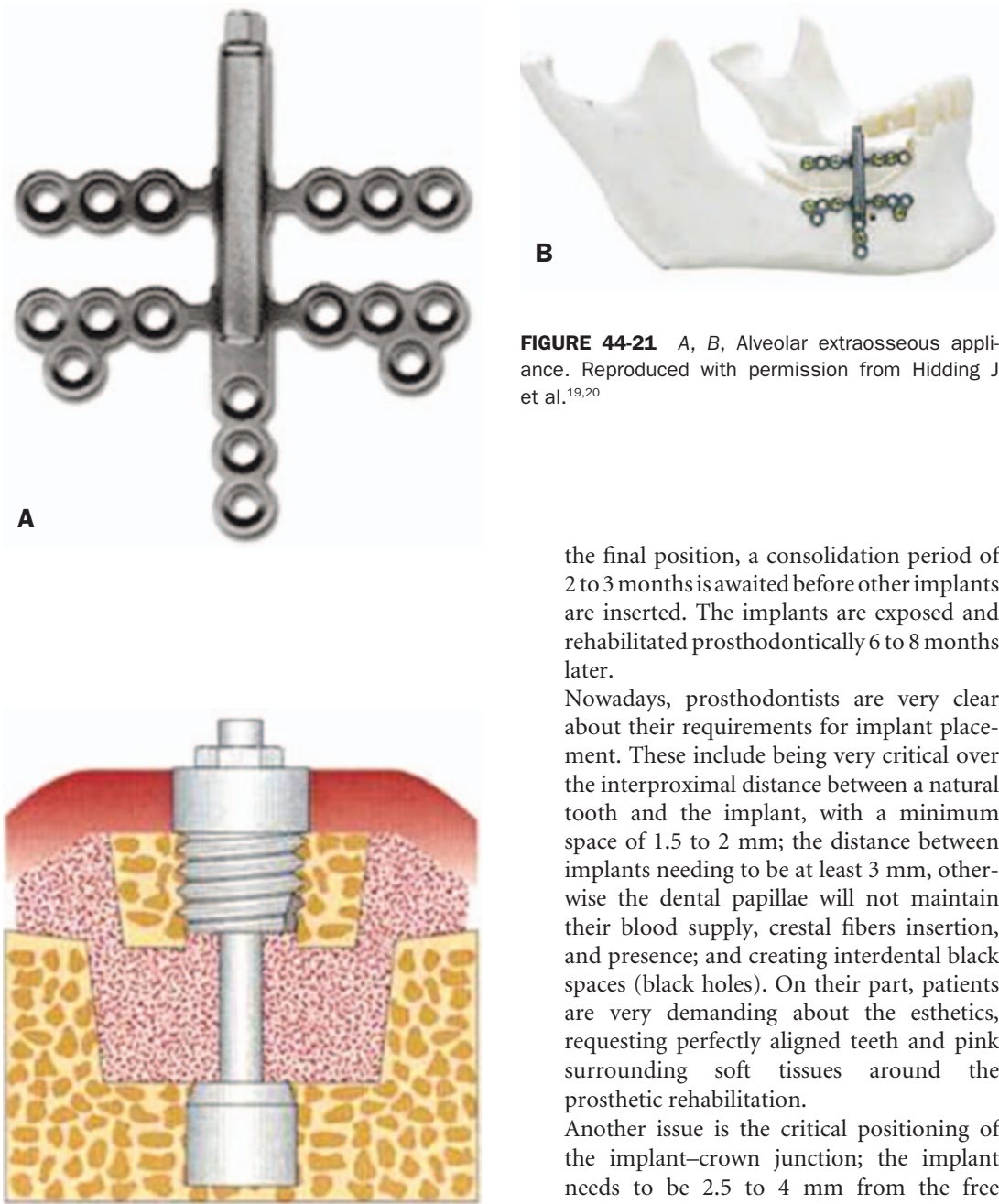


FIGURE 44-21 A, B, Alveolar extraosseous appliance. Reproduced with permission from Hidding J et al.^{19,20}

the final position, a consolidation period of 2 to 3 months is awaited before other implants are inserted. The implants are exposed and rehabilitated prosthodontically 6 to 8 months later.

Nowadays, prosthodontists are very clear about their requirements for implant placement. These include being very critical over the interproximal distance between a natural tooth and the implant, with a minimum space of 1.5 to 2 mm; the distance between implants needing to be at least 3 mm, otherwise the dental papillae will not maintain their blood supply, crestal fibers insertion, and presence; and creating interdental black spaces (black holes). On their part, patients are very demanding about the esthetics, requesting perfectly aligned teeth and pink surrounding soft tissues around the prosthetic rehabilitation.

Another issue is the critical positioning of the implant–crown junction; the implant needs to be 2.5 to 4 mm from the free gingival margin (above in the maxilla and below in the mandible in the esthetic zone) to allow the prosthetic crown to emerge

FIGURE 44-22 The implant distractor. Reproduced with permission from McAllister BS.²²

naturally from the gingival tissues. Zirconium abutments have been a major advancement in the esthetic zones, because their light color will show through the gingival tissues very naturally, extending the life span of the prosthesis.

Prosthodontists will consider a compromised implant in the esthetic zone as being unacceptable, as such a situation will limit the final detailed and meticulous outcome of the treatment. Most prosthodontists will not assume the responsibility to rehabilitate an implant that requires a cantilever in excess, or compromise the periimplant hygiene after crown insertion, leading to periimplantitis and failure.

The internal replaceable device^{23,24}: In this approach, an incision is made deep in the sulcus, a complete osteotomy is performed, the segment to be transported is fixed internally to a transport and a basal plate. The periosteal layer is carefully sutured, and the appliance is activated out on the alveolar crest after the latency period has been concluded (Figure 44-23).

Even though it is a unidirectional device, different simple maneuvers could be used to change the vector after the surgery. The distraction rod is removed 8 to 12 weeks later,

by unscrewing the head, once the implants are placed transmucosally to stabilize the transported segment to the basal bone, avoiding micromotion that compromises healing of the distraction chamber during the consolidation period. The microplates could be left in place, eliminating the need for a second surgical stage. It is technique sensitive, but the most comfortable device available.

3. The hybrid distractor consists of two bondable attachments and a horizontal rod that spans the distraction site. Although the device is hybrid, it is principally toothborne supported, with only a fixation wire attached to the transport disk, and no screws are required. It is the first option for a single-tooth defect; the available devices are too big for the little fragment that needs to be mobilized (Figure 44-24).²⁵

The current approach for alveolar distraction includes avoiding extensive periosteal stripping to place the distractor, especially if it is interposed between the periosteal layer and the bone. It may not allow saliva and food contamination into the distraction chamber, and the vascularity of the moving segment cannot be compromised because this limits the bone formation underneath the appliance. The device must permit vector changes after surgery. There have been improvements in the designs of many distractors to change the vector in the postoperative period.

Ideally, no reentries are indicated to avoid soft and hard tissue shrinkage postsurgically. A surgical variation, to avoid major periosteal stripping and distraction chamber contamination, is to place the distractor transmucosally after soft tissue water-tight closure over the distraction chamber.

Finally, the size and location of the device make the difference in patient comfort.

Surgical Technique

Under intravenous sedation, local anesthesia with a vasoconstrictor is infiltrated in the buccal vestibule, and a 2 to 3 cm horizontal mucoperiosteal

incision is made, depending on the defect extension. The periosteum is minimally elevated at the osteotomy sites, and proper retractors are used to expose the bone, taking special care to not strip the bone. The lingual or palatal mucosa should not be detached from the bone, under any circumstances, to optimize the distraction chamber healing process (Figure 44-25).

A No. 701 bur mounted on a drill is used under abundant irrigation, to avoid bone overheating, and the osteotomy limits are demarcated in the buccal cortex, the horizontal and vertical components of the design. A microsaw is then used to continue the horizontal bony cuts. Tunnels are used to minimize the soft tissue elevation. Before completing the osteotomy, it is highly recommended to use a 1.5-mm-long shaft bur in a straight handpiece to debilitate the palatal cortex through the horizontal osteotomy, assuring that the segment fractures at the planned level. Inadvertent pressure over the frontal segment will cause a natural fracture in the weakest area, separating the buccal from the palatal cortices. In this event, the surgery is aborted and postponed until adequate healing has happened, usually around 3 to 4 months, before a new alveolar distraction is indicated.

Completing the osteotomy of the distraction segment is gently finalized with a fine spatula or curved osteotome for the anterior maxilla, protecting the palatal or lingual mucosa with a finger and producing an approximately 4 mm separation at the base to allow the placement of the intraosseous appliance.

The distraction rod is inserted through the mucosa in the center of the alveolar crest, using the surgical guiding splint previously made on the model surgery for vector assessment. The distractor length is selected based on the prosthetic wax-up, allowing 20 to 30% of overcorrection in the vertical and A-P dimensions. The transport plate is placed at the chamber, held in with a wire holder while the rod is introduced from the crestal drilled hole to the chamber and is twisted to engage the transport plate. After correct engagement, the transporting plate is bent toward the transport segment and is fixated with two 1.2×5 mm screws. The next step is to introduce the base plate into the chamber to receive the rod end; when the distraction vector is achieved, the base plate is bent toward the basal bone and fixated with another two 1.2×5 mm screws (Figure 44-26). The appliance is activated to verify its function, and the "Y"-shaped vector control plate is placed over the palate, fixating the short arms of the plate transmucosally in the palate, while the longest straight portion of the plate receives the rod to maintain the vector during the whole distraction process.¹⁷ This plate must be previously contoured over the model surgery wax-up, taking special attention to bend in at an

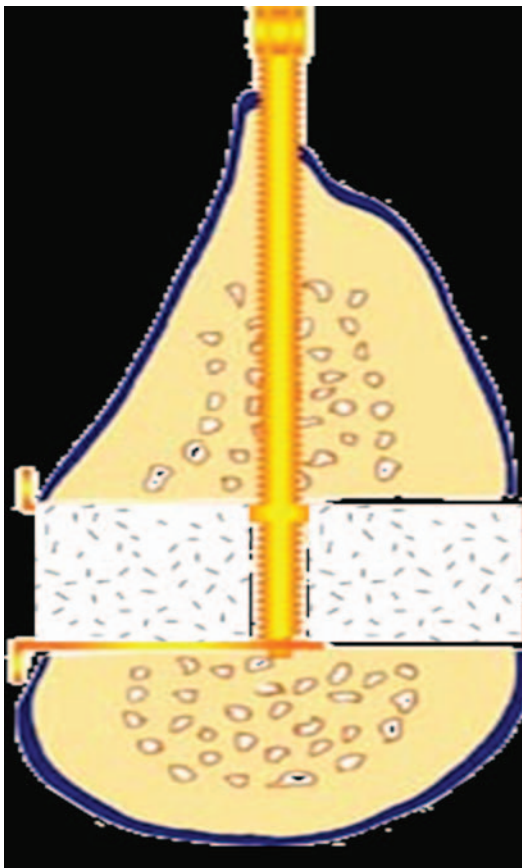


FIGURE 44-23 The Leibinger endosseous alveolar distraction (LEAD) internal distractor. Reproduced with permission from Chin M.²³



FIGURE 44-24 The Rod-5 hybrid distractor. Reproduced with permission from Razdolsky Y et al.²⁵

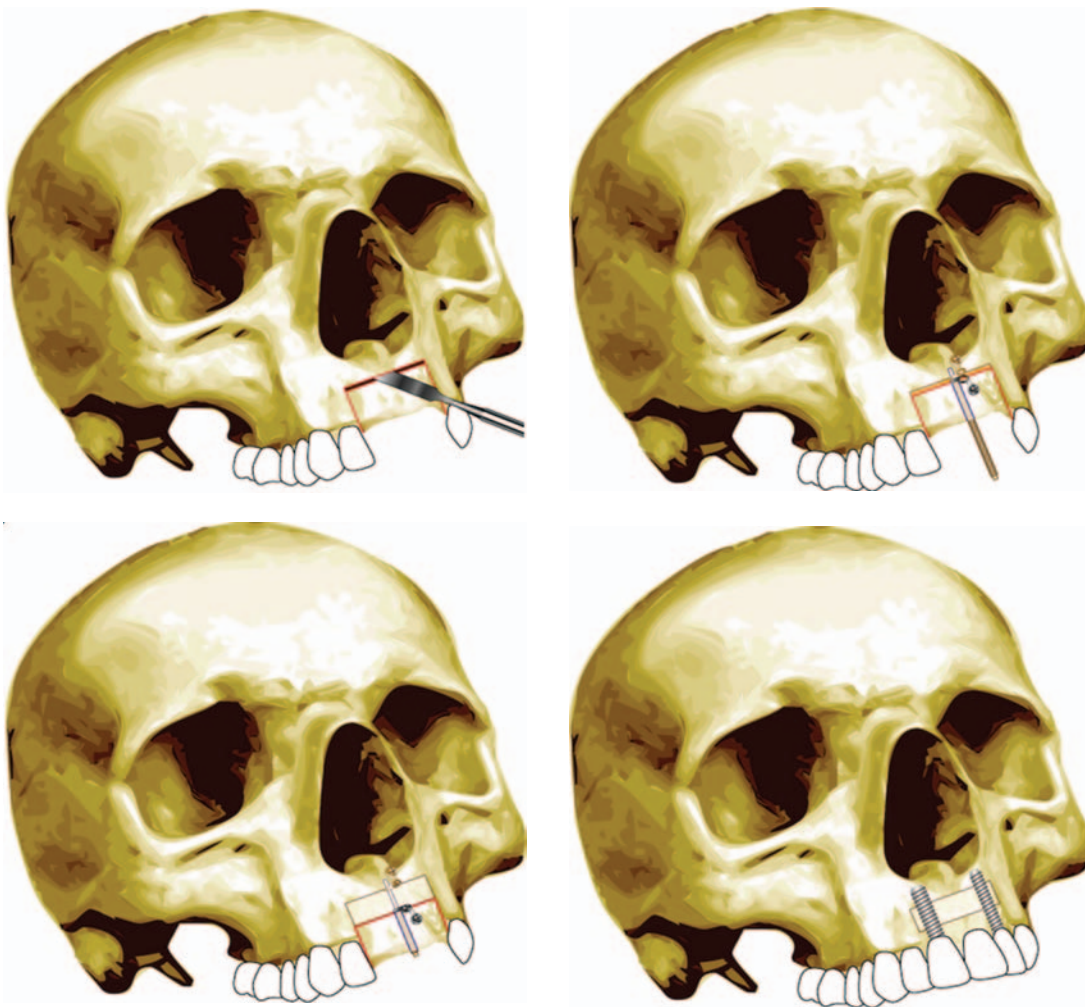


FIGURE 44-25 Phases of alveolar distraction treatment.

acute angle (to the buccal) the final portion of the plate containing the hole that receives the rod. This would allow displacement of the transport disk in the desired direction. Finally, a layer suture with a water-tight mucosa closure is performed in the sulcus incision (Figure 44-27).

Distraction Protocol

1. Complete segmental osteotomy: The bone cuts are a complete osteotomy, through and through, maintaining the soft tissues attached as much as possible for adequate vascularization.
2. Latency period: After surgery, it is fundamental to wait 7 days without any activation to allow the collagen type 1 fibers to form at the distraction chamber. These fibers develop between 5 and 6 days after the osteotomy.
3. Activation period: This starts on the seventh day, until the transporting disk reaches the planned movement on the prediction wax-up with 20% of overcorrection.
4. Rate and rhythm: 0.5 mm twice a day or 0.5 mm a day, in older, medical compromised patients, or even when the distraction segment is very small, the rate should be lower. More than 1 mm a day produces rupture of the collagen fibers leading to weak and deficient bone formation.
5. Consolidation period: The consolidation period for complete mineralization extends for 10 to 12 months. Histologically, at 8 weeks, very active remodeling is present throughout the distraction regenerate. Newly formed viable vascularized bony trabeculae contact both sides of the distracted bone edges and are surrounded by proliferating osteoblasts. The orientation of the bone trabeculae is parallel to the direction of the distraction.
All of the spaces are filled with a network of relatively dense osseous trabeculae that are actively perforated by newly formed blood vessels.
6. Implant placement: The implants are placed transmucosally 14 to 24 weeks after distraction surgery. The fixture length is chosen according to the total length that includes the transported bone, the distraction chamber, and the basal bone. The first and second fixtures have to be in position before the distractor pin is removed, to fixate the bony segment during the consolidation period (Figures 44-28 through 44-29). The position of the fixture head determines the biologic attachment of the gingival tissues to the implant. In an ideal situation, this level



FIGURE 44-26 Intraoral views of a 52-year-old partially edentulous female patient with a severely atrophic anterior maxilla, and posterior maxillary and anterior mandibular segments extrusion.

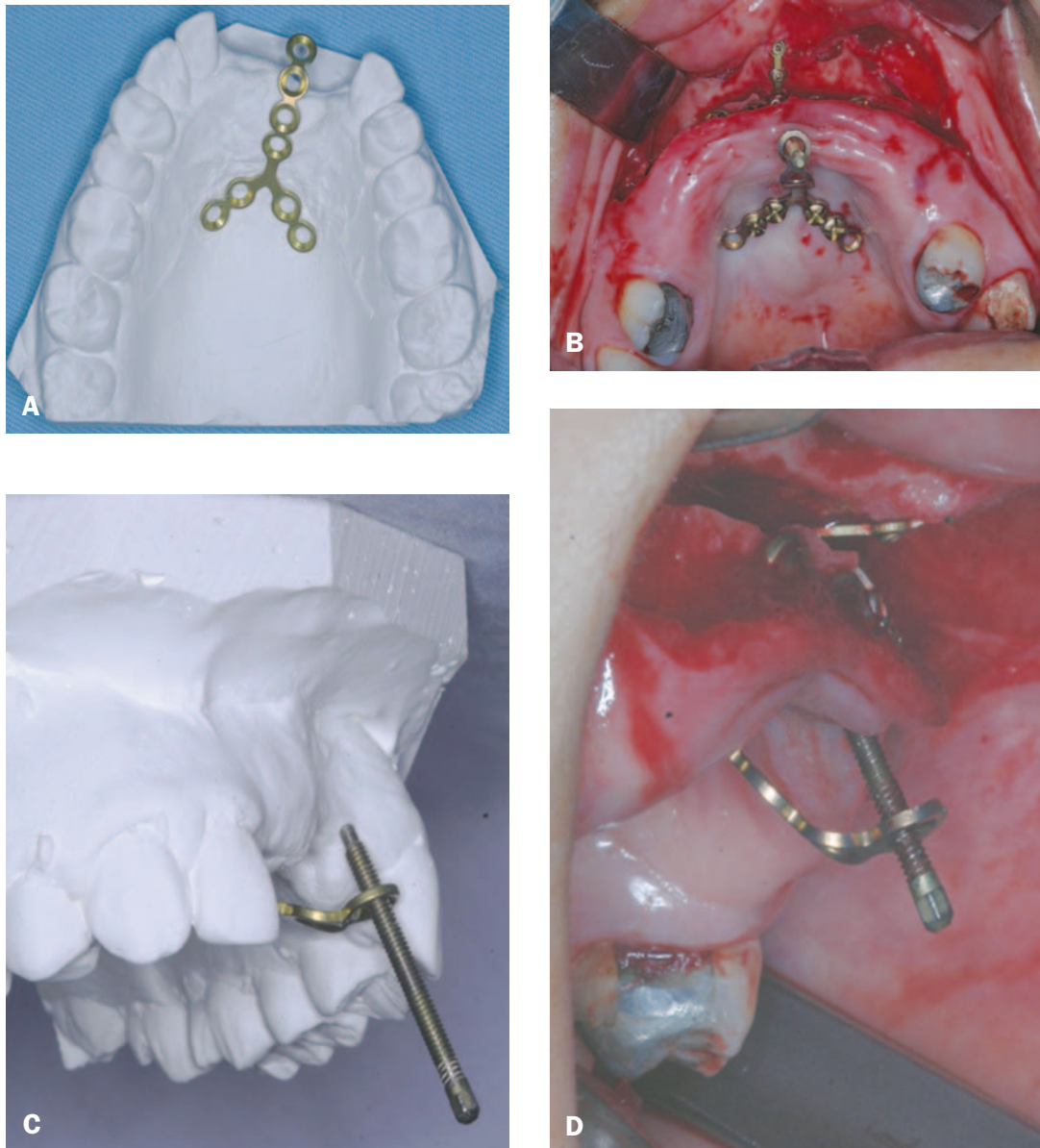


FIGURE 44-27 Vector controller plate. *A*, The distractor is properly placed, but the hard palatal mucosa will bend the segment posteriorly, causing deficiencies in the anteroposterior projection of the alveolus. *B*, The palatal plate is fixated transmucosally, and the adaptation is prepared in the presurgical work-up over the models mounted in a semi-adjustable articulator. *C*, *D*, Observe the separation from the alveolar crest.

should correspond to the junctional epithelium level on the adjacent teeth. Microplates could be left in place to eliminate the need for a second open surgical stage, or a small incision can be made at the end of the vestibule to remove the base and transport plates. In addition, if further soft tissue or bone augmentation is needed in the buccal side, either a connective tissue graft or a mixture of bone collected from the suction tramp and alloplastic materials with a collagen membrane is layered over, using a sulcus approach. After implant placement, healing caps are screwed over, a horizontal mattress suture is placed around every implant, and the area is sealed with N-2-butylcyanoacrylate (Periacyrl) to enhance the biologic closure and to avoid food and bacterial contamination during the initial healing phase.

In this remodeling period, the implants are placed to parallel with distraction healing and osseointegration.

This sequence reduces treatment time and stimulates the alveolar reconstruction, with stable and predictable outcomes (Figures 44-30 through 44-32).

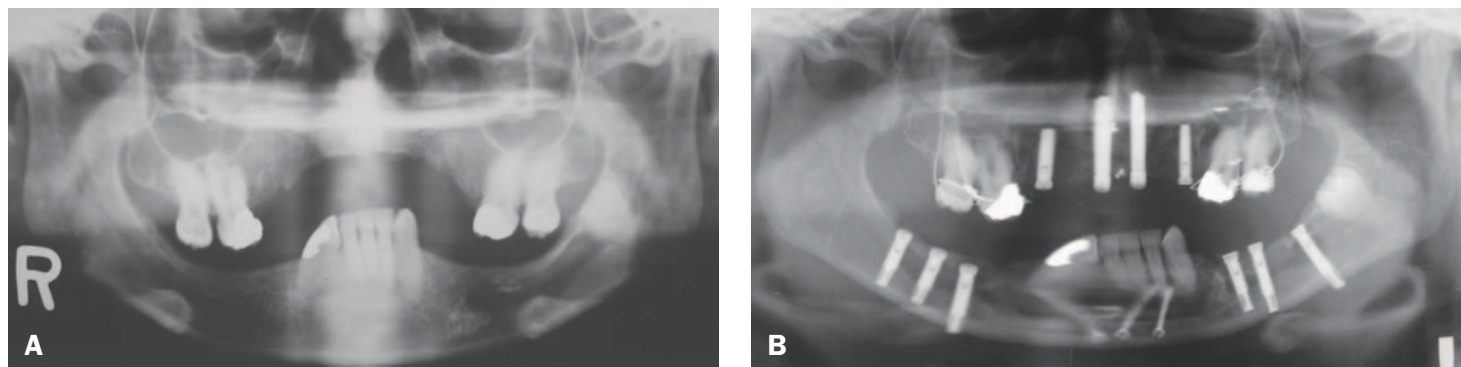


FIGURE 44-28 Panoramic radiographic sequence. *A*, Preoperative view; observe the severe anterior maxillary deficiency. *B*, Postoperative view. Note the mandibular anterior sub-apical osteotomy, posterior maxillary superior repositioning and the implants in place, after distraction osteogenesis and inferior alveolar nerve lateralization.



FIGURE 44-29 Lateral cephalic sequence. The anterior mandible and posterior maxilla were repositioned by segmental osteotomies, while the distraction osteogenesis developed the bone for dental implants. Note the implants going through the transported bone, the distraction chamber, and the basal bone. The vector control rigid plate improved the distractor stability and enhanced bone healing.



FIGURE 44-30 A, Preoperative frontal view. B, Postoperative frontal view. Observe the clinical situation after segmental maxillomandibular osteotomies, distraction osteogenesis, implants placement and prosthodontics.

Posterior Mandibular Alveolar Distraction

The posterior mandibular area requires some specific considerations in the surgical planning and technique, primarily because of the presence of the inferior alveolar nerve and the remaining basal bone, and secondly, because it represents a more difficult surgical access that demands high degree of skill and experience with alveolar distraction techniques. Furthermore, the intermaxillary relation is of paramount importance, as there is a need to consider the transverse as the vertical relation. Dentals models mounted in an articulator help the clinician to understand and measure the requirements of the bone movement. Unpredictable distraction will finalize the alveolar positioning and implants where the prosthodontist will not be able to construct the dental rehabilitation.

We recommend general anesthesia for posterior mandibular distraction, because the difficult access and proximity of the inferior alveolar nerve.



FIGURE 44-31 Pre-(A) and postoperative (B) lateral views.

In long segments, inclination of the distraction disk occurs during activation because of the difference in strength of the surrounding soft tissue. The use of two parallel distractors is highly recommended to provide stability and to perform a controlled activation on either side of the defect, thereby avoiding extreme overcorrection in one side and deficiency in the other side.¹⁶

Generally, the posterior mandibular alveolar deficiency requires more vertical augmentation in the premolar area than posteriorly. The solution is to place one distractor in the deficient area while a three hole microplate is fixated in the back permitting disk rotation during activation. In these cases, the osteotomy needs to be performed in a triangular fashion to allow for segment mobilization (Figures 44-33 and 44-34).

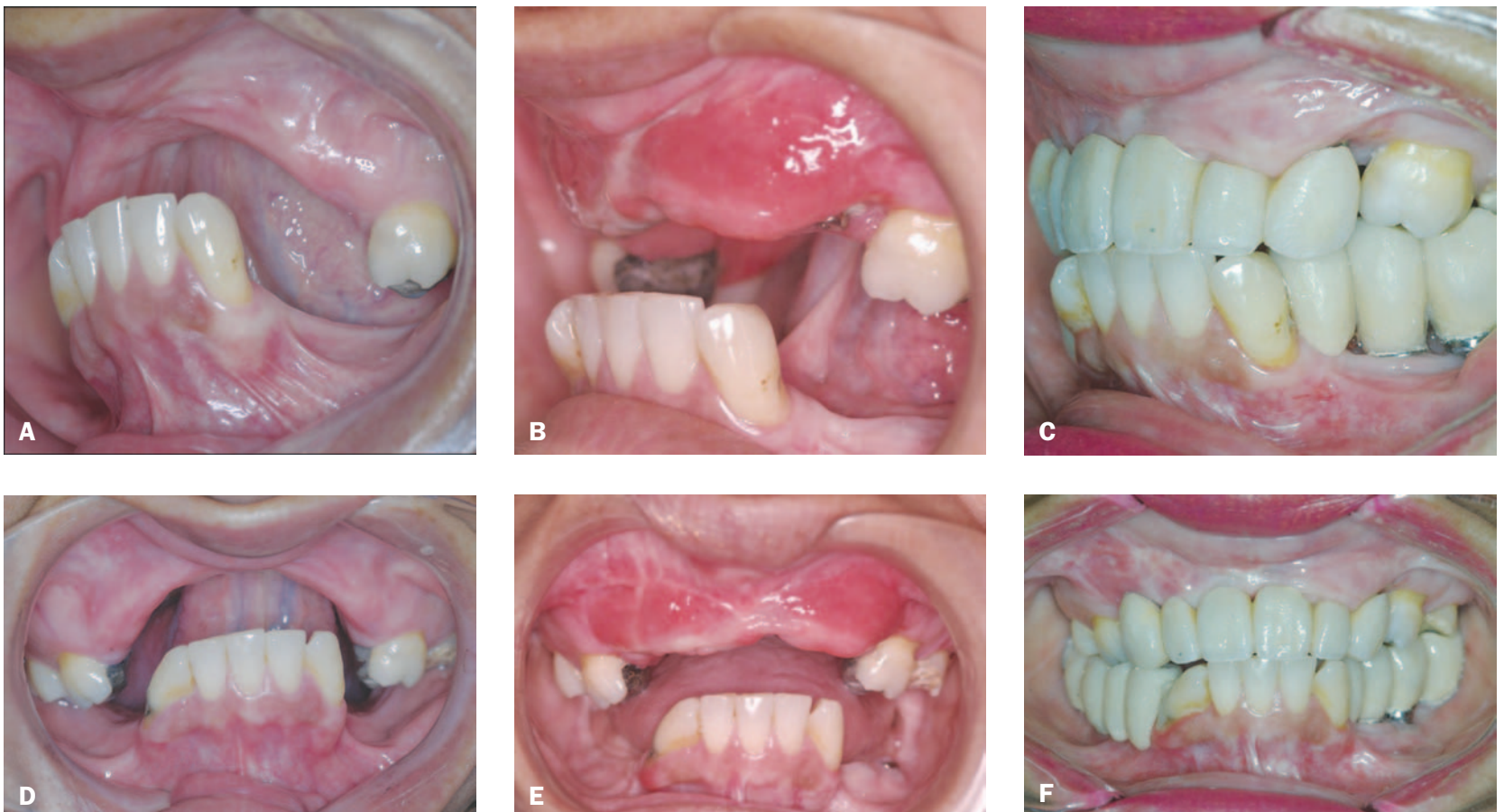


FIGURE 44-32 A, D, Lateral and frontal intraoral preoperative views. B, E, Observe the three-dimensional alveolar reconstruction by distraction osteogenesis. C, F, Lateral and frontal intraoral postoperative views. Prosthetic rehabilitation.

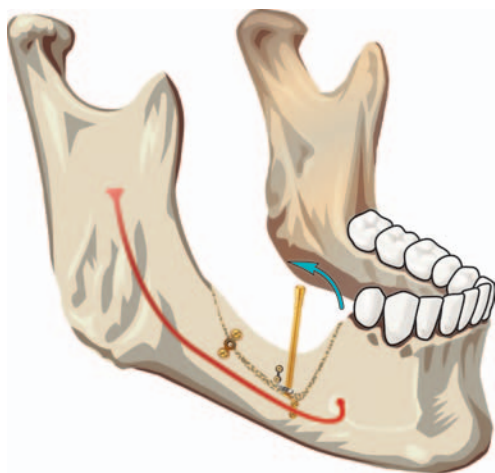


FIGURE 44-33 Bilateral asymmetric posterior mandibular atrophy. The patient was aware of possible nerve damage during implant placement. He also had posterior maxillary extrusion, the ideal indication for asymmetric alveolar distraction, using a 3-hole plate posteriorly, thus allowing elevation of the segments in the premolar area only.

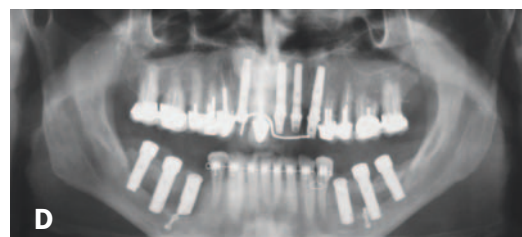
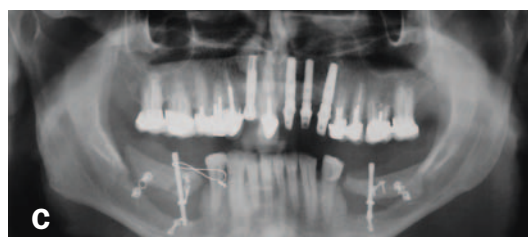
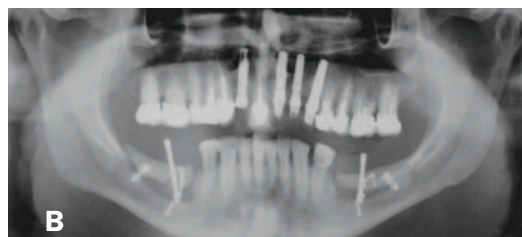
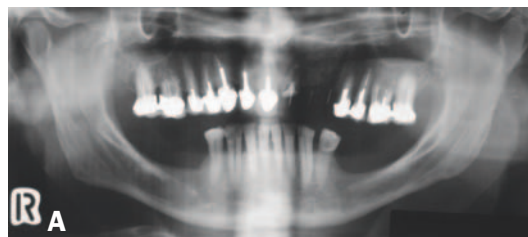


FIGURE 44-34 Panoramic radiographic sequence. A, Preoperative. Observe the bilateral posterior mandibular asymmetric deficiency. B, Immediate postoperative view. Note the osteotomy shape with the distractors and microplates in place. C, Observe the new alveolar vertical position after distraction osteogenesis. D, Twenty weeks later, the implants were placed. The distraction base plates were left in place. The rod and transport plates were removed.

Another consideration in the posterior mandible is to postpone implant placement until consolidation of the distraction chamber has been achieved (a minimum of 6 months), bearing in mind that the fixtures should not reach the basal bone to stabilize the segment during the consolidation period because of the presence of the inferior alveolar nerve. In other alveolar areas, the implants are placed earlier to shorten the total treatment time, as they stabilize the transported segment to the basal bone in the new position while chamber mineralization and fixture osseointegration occur simultaneously (Figures 44-35 through 44-36).

Most Common Mistakes

Distraction osteogenesis to reconstruct the deficient alveolar ridge is a predictable technique that

allows soft and hard tissues regeneration to place implants in an ideal situation that will satisfy today's state of the art in prosthetic rehabilitation, both esthetically and functionally. However, the treatment plan needs to be a combination of disciplines: prosthetics, periodontics, orthodontics, and surgery, or at least a good understanding of the principles involved in the ideal teeth, bone, and soft tissues relationship. If the planning is not prosthetically guided, then a disastrous final outcome will be achieved. Re-interventions in the alveolar region are to be avoided, because poor vascularity, fibrous tissue presence, and nonvital bone are often encountered; the results after reoperations are unpredictable; and the possibility of a major segment loss is high.

The most common mistakes in alveolar distraction could be summarized as follows:

1. **Poor indication:** The best treatment option is the simplest one that corrects the patient's problem list. For example, in a totally edentulous patient with a very atrophic mandible, the conventional Brånemark protocol, using long and wide implants, will produce predictable functional and esthetic results in a short period of time, enabling the patient to resume his/her normal physiologic and social activities soon after surgery. Distraction osteogenesis in these cases could result in basal bone fractures, poor nourishment, infection, and depression, and should not be considered as an alternative.
2. **Devascularization of the segment:** The periosteal layer is responsible for 60% of the healing process, hence the surgery needs to be performed inside this envelope and sutured back carefully. Distraction osteogenesis follows different biologic principles than free grafts, and the periosteum must be attached to the transport disk to assure predictable augmentation. Quite often, the surgeon strips the bone to be distracted from the periosteal layer; the moving bone is transformed into a free graft, with different levels of resorption after surgery.
3. **Inadequate soft tissue management:** A wound dehiscence compromises the osteogenic and histogenic processes, hence it is mandatory to delay the activation and recreate the optimal environment for the healing before continuing with distraction. After mineralization of the distraction chamber, the soft tissue deficiencies could be managed with a variety of surgical techniques, such as use of keratinized gingival grafts, connective tissue grafts through a sulcus approach, and vestibuloplasties, to improve the esthetic results.

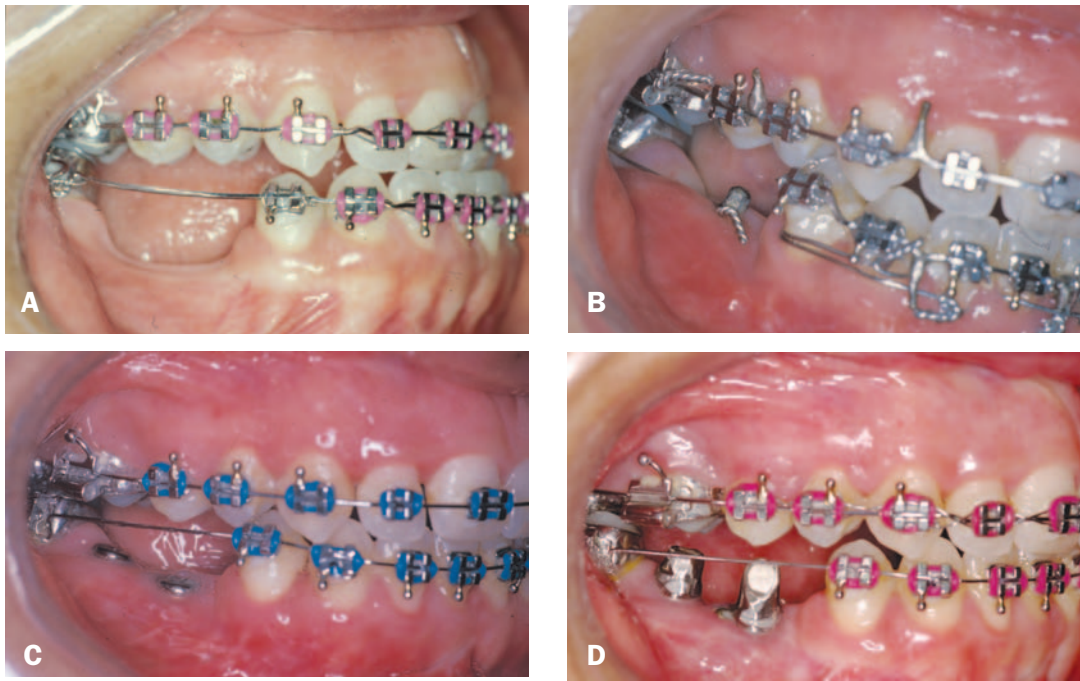


FIGURE 44-35 Orthognathic surgery patient with a Class III malocclusion, presenting with a severe “hamac” type mandibular atrophy. The segment was elevated 7 mm, and 15-mm-long implants were inserted in a flapless fashion 5 months after alveolar distraction.

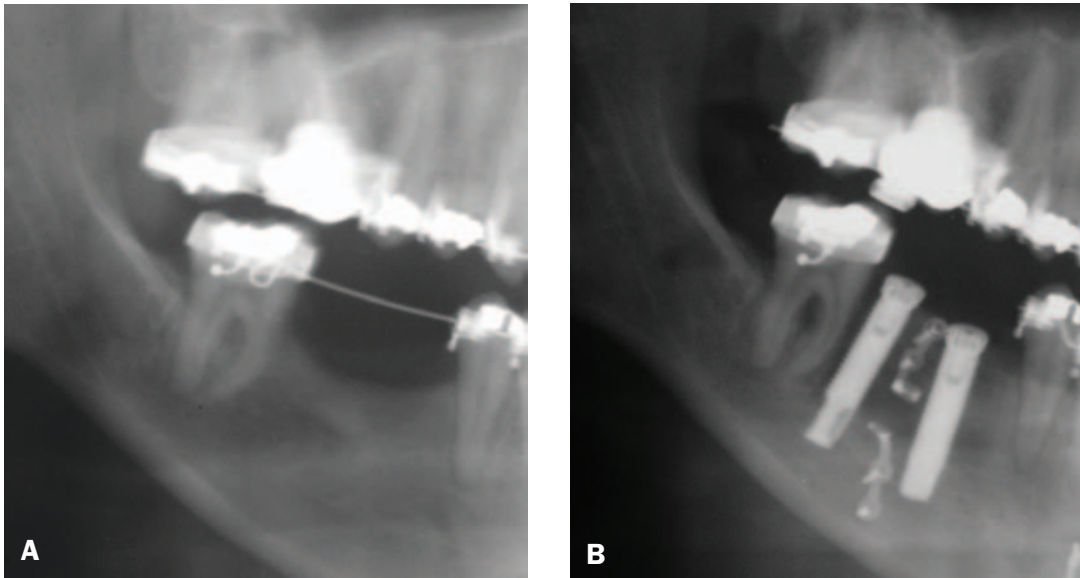


FIGURE 44-36 A, Preoperative radiographic view. B, Postoperative radiographs showing the distraction plates left in place, with only the rod removed, and fixtures inserted flapless.

4. **Incorrect distraction vector:** The prosthetic guided planning based on photographs, radiographs, and dental model wax-up, and the making of a surgical splint are essential for maintaining the desired vestibular angulation during the drilling process. Different maneuvers have been described to control the distraction vector with the internal devices during the activation and consolidation periods. The use of the vector control plate enhances the appliance stability

and bone healing, and improves the vector maintenance, thereby avoiding the palatal mucosa from pulling backwards during distraction. If the distraction segment mobilizes away from the planned positioning, poor esthetic results will be encountered, forcing the prosthodontist to camouflage the poor inclination of the dental implants, and the soft tissues will be absent with the inability to create a natural, good-looking dental-gingival appearance.

5. **Incomplete distraction:** When a 20 to 30% of three-dimensional overcorrection to compensate for periosteal retraction is not considered, or inadequate surgical planning occurs, the outcome will be insufficient to ideally reconstruct the deficient alveolar ridge and poor results will be obtained with the dental rehabilitation. This problem can be avoided by selecting the proper distraction rod, and exercising good surgical planning, and complete activation up to overcorrecting the alveolar region. The distraction rod is selected with a few millimeters in excess, and it is cut off at the gingival level once the desired position has been reached during the activation phase.
6. **Fixture placement:** The implant phase must be meticulous and detailed, to fixate the distracted segment to the basal bone with adequate long implants. Before the distraction rod is removed, a stable bone recipient is fundamental. The implants are to be placed in the ideal position, carefully guided by the prosthodontic splint.
7. **Need for re-intervention:** A reentry before the complete mineralization of the chamber is contraindicated and needs to be avoided, because it interrupts the healing process, causing callous contraction and fibrous tissue formation. In particular situations, extra augmentation is needed; this must be delayed until proper distraction consolidation has occurred. At 4 to 6 months after the distraction surgery, the sulcus approach is the ideal access to place bone grafts, fixed with miniscrews or connective tissue grafts.
8. **Distraction osteogenesis after bone grafting:** Previous failures with traditional bone grafting techniques do not indicate distraction osteogenesis, following the biologic principles of distraction osteogenesis, where blood supply and non-scar tissue play a major role in the healing capacity. Other variables such as the age of the patient, quantity and quality of the tissues, and magnitude of movement are to be taken into consideration.

Immediate Alveolar Distraction

For moderate alveolar defects (4 to 7 mm in the vertical dimension), immediate alveolar distraction with simultaneous transmucosal implants could be performed in the non-esthetic area. This approach is indicated when the interocclusal space is increased to improve the crown-to-implant ratio and to avoid major steps in the marginal gingival contour between the adjacent teeth and the new implants (Figures 44-37).²⁶⁻²⁸

The surgical technique involves a horizontal incision deep in the sulcus, minimal periosteal elevation, and osteotomy of the transport

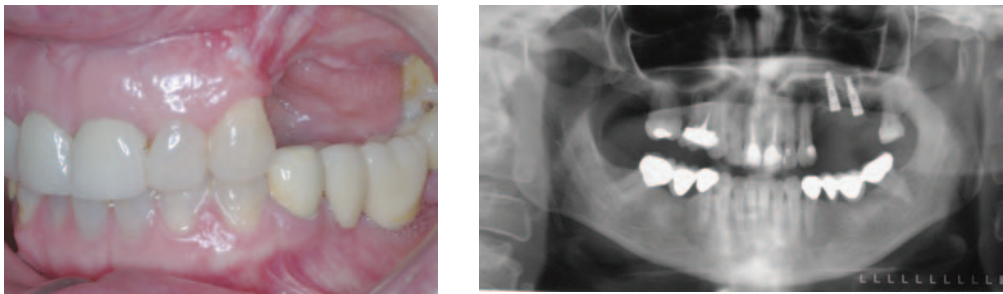


FIGURE 44-37 Severe maxillary atrophy and major step at the cervical area after traditional free grafts and implant placement. The implants failed and had to be removed.

prosthodontist must assemble a plan together and consider all the different variables.

Distraction osteogenesis offers the possibility to place dental implants in a proper position to obtain excellent prosthetic results. Most of the complications can be prevented, and those appearing during the postoperative period can be easily corrected because of the nature of progressive changes. Alveolar distraction osteogenesis offers a predictable bone and soft tissue augmentation.

segment under abundant irrigation, as in conventional alveolar distraction.

After the osteotomy has been completed, the implant drilling is made through the distraction segment and 3 mm into the basal bone, using the prosthetic guiding splint. The implants are slowly screwed in progressively, allowing the two bone segments to separate; a strong hook is used to mobilize the segment toward the palate or buccally, permitting the long dental implants to stabilize the distracted bone (Figure 44-38).

The healing abutments are placed, and a microplate could be used in the buccal aspect to enhance fixation of the distracted bone to the basal bone.

Bone graft, harvested either locally (mandibular ramus or symphysis) or from the tibia, is used to fill the newly created chamber.

The wound is closed in two layers to avoid saliva and food contamination into the chamber, and if it is necessary, releasing periosteal incisions are made to insure a tension-free closure.

A challenging situation may present in the posterior maxilla, when critical millimeters of bone are left; here, a sinus lift is recommended to assess the actual basal segment height and to guarantee bone roof anchorage for immediate implant alveolar distraction, having direct visualization (Figure 44-39).

Conclusions

Distraction osteogenesis is an alternative in moderate to severe alveolar deficiencies for an ideal three-dimensional reconstruction. This surgical technique allows for implant placement and final prosthetic restoration in a healthy tissue environment. It requires a prosthetic-oriented planning, three-dimensional overcorrection, meticulous surgery, and a strict postoperative protocol. The method is very sensitive to the protocol and planning, hence the surgeon and

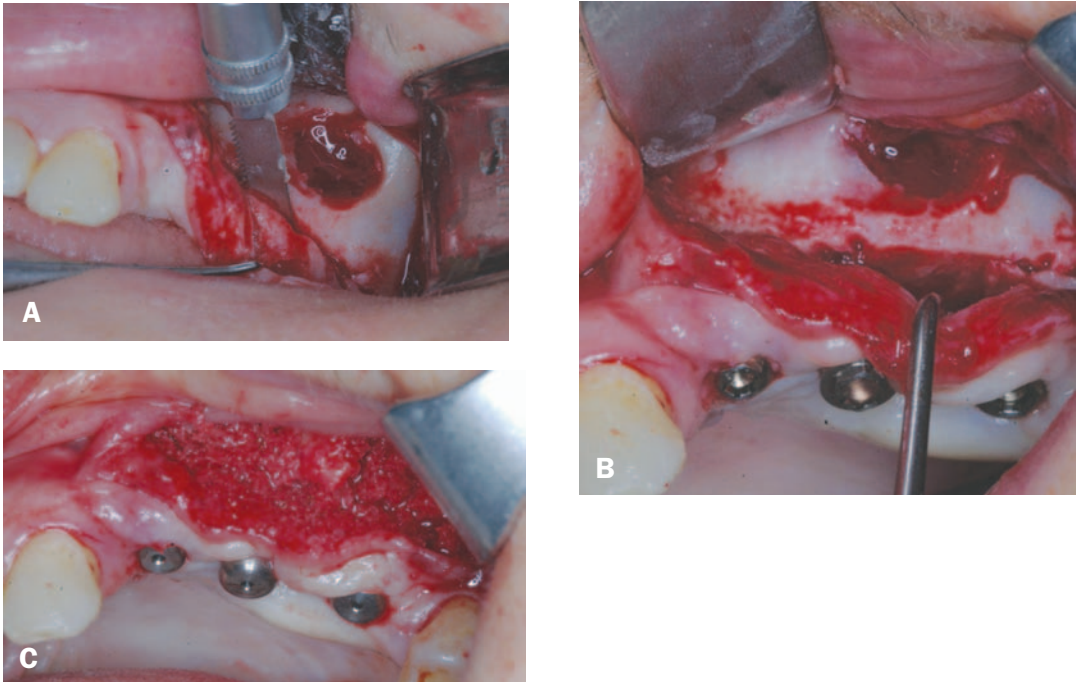


FIGURE 44-38 A, Lateral maxillary window and sinus membrane elevation was performed in a standard fashion; a horizontal osteotomy was completed under abundant irrigation with a microsaw, for alveolar segment vertical displacement. B, The transported segment was stabilized while three fixtures were inserted transmucosally through the displaced bone, the directly created distraction chamber, and the basal segment (2/3) into the maxillary sinus (1/3). C, Bone collected from the lateral tibia was packed into the chamber and the maxillary sinus.

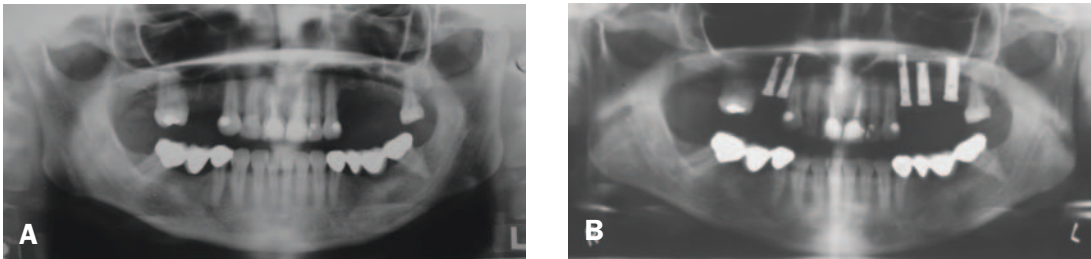


FIGURE 44-39 A, B, Pre- and postoperative radiographs showing the left posterior maxillary deficiency and the obtained implant positioning.

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Alveolar Distraction for Height and Width

Zvi Laster and Ole T. Jensen

The principle of distraction osteogenesis, derived from the orthopedist Ilizarov, has been demonstrated for alveolar modification.¹⁻⁴ Alveolar bone can be distracted in all directions to gain both height and width. Alveolar small bone fragment distraction is done once or twice per day in 0.4 mm increments, well below the 1 to 2 mm per day used in long bones.³⁻¹⁶

The most common use of distraction in the oral cavity is for vertical alveolar augmentation. Unique to vertical alveolar distraction are the investing oral tissues that must be preserved on the transport segment. As the bone is moved away from basal bone, the transport is “pulled” lingually by the pedicle. For leg lengthening, Ilizarov used opposing distractors to counterbalance distraction force. For alveolar distraction, an opposing device cannot be placed as it will disturb periosteal blood supply to the segment. One solution for this vector problem is to use a bidimensional device, such as the Mommaerts/Laster crest distractor (Surgi-TeC, Brugge, Belgium) illustrated in Figures 45-1, 45-2, and 45-3. With this device,



FIGURE 45-1 A vertical alveolar defect involving both a vertical and a horizontal component.

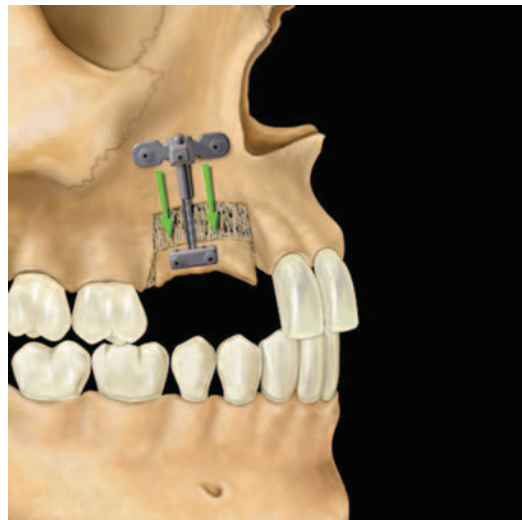


FIGURE 45-2 An alveolar segmental osteotomy is distracted into the orthoalveolar position and left to heal for 4 months.



FIGURE 45-3 Dental implants are restored after osseointegration occurs, with the implant passing through the distraction zone.

a vertical movement is made and then followed by horizontal movement to compensate for lingual or palatal deflection.⁵

In case 1, a 34-year-old female presented with missing maxillary anterior incisor teeth owing to trauma from a motor vehicle accident (Figure 45-4). She desired implants. The defect appears at first glance to be minimal. However, a critical appraisal of the bone morphology (Figure 45-5) reveals nearly complete loss of the facial plate of bone and a 4 to 5 mm horizontal



FIGURE 45-4 Preoperative view shows a vertical defect.



FIGURE 45-5 Preoperative view demonstrating a horizontal defect.

defect, combined with a 3 mm alveolar vertical deficiency. This diagnostic conclusion discards the previous notion of “sufficient bone to restore” in favor of a desire to recover alveolar anatomy, a reestablishment of orthoalveolar form.

In this setting, the maxillary segment was distracted vertically 3 mm and then horizontally about 5 mm (Figure 45-6). Following a healing period of 4 months, the device was removed and dental implants were placed.

The patient was restored with a four-tooth bridge on four implants (Figure 45-7). Resonance frequency analysis (RFA) was used to help determine the viability for single tooth restoration. RFA values in distraction sites are generally lower than those in native bone, as in this case, so a splinted restoration was done.



FIGURE 45-6 Occlusal view shows 5 mm horizontal movement.



FIGURE 45-7 Final restoration.

In case 2, a 50-year-old male presented with a six-unit anterior maxillary bridge. He desired implants to replace an unaesthetic restoration (Figure 45-8). There was marked atrophy of both soft and hard tissues, leaving a significant alveolar retrognathia.

The initial treatment was to reduce the existing temporary bridge to a more anatomic dental shape and form, which shortened the teeth and made space for papillae interdentally. Figure 45-9 shows how the modified temporary bridge demonstrates the underlying vertical and horizontal defect, which in this case was about 5 mm horizontally and 10 mm vertically. The modified temporary establishes the “target” and desired “vector” of distraction.

The bidimensional device was placed through a vestibular incision, taking care not to disturb



FIGURE 45-8 Preoperative view (Case 2).



FIGURE 45-9 Modified temporary bridge demonstrates the underlying defect.

the investing tissue of the transport segment. After vertical distraction (Figure 45-10), the segment engaged the temporary but was “pulled” palatally (Figure 45-11). The bidimensional device enabled a straight horizontal movement of about 5 mm and restoration of orthoalveolar form.

In this case, exposure of the site 4 months later enabled soft tissue manipulation and implant placement so that the final restoration closely approximated papillary form in this four-implant restoration (Figure 45-12). The lateral view (Figure 45-13) demonstrates a natural-appearing alveolar projection.



FIGURE 45-10 After 10 mm vertical distraction.



FIGURE 45-11 Palatal movement of the transport segment before it is brought forward horizontally.



FIGURE 45-12 Final four-implant restoration.



FIGURE 45-13 Final restoration; lateral view demonstrates alveolar projection.



FIGURE 45-14 Crest widener (first prototype) and activating spanner, designed by the first author.

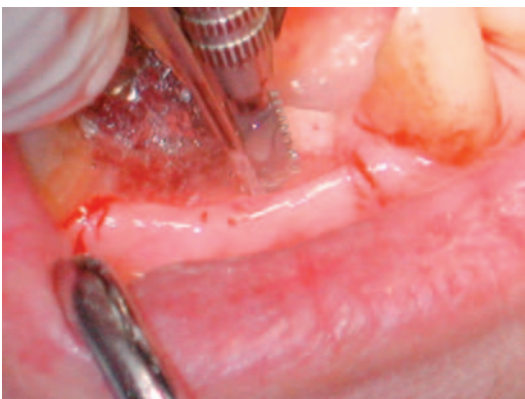


FIGURE 45-17 Cutting-through incisions using a scalpel saw.

Cases 3 and 4 demonstrate a special situation in which vertical height is present, but there is insufficient width. The facial plate of bone presents in a more lingual position. This lingualized buccal alveolar position is a typical resorption pattern that occurs in both the maxilla and the mandible. Early postextraction sites usually maintain vertical crestal height owing to this, but width is almost always lost and may eventually be insufficient for implant placement without bone augmentation.

Crest widening by distraction in this setting is a useful alternative to guided bone regeneration or block grafting. Distraction osteogenesis also provides for distraction histiogenesis, that is, soft tissue expansion, particularly an increase in attached gingiva. Implant placement is recommended within 4 to 6 weeks after distraction, a relatively short period of time when compared with other grafting approaches.

The surgical procedure for crest distraction has the important advantage of stability of both hard and soft tissues. The transported facial plate does not resorb significantly. The minimum ridge width for this technique is about 5 mm when using a saw but perhaps as thin as 3 mm if piezosurgery is available.

The crest widener consists of four sharp arms, two on each side, connected by two activating screws, two guiding pins, and a spanner to activate the device (Figure 45-14). It is inserted through a crestal incision (Figures 45-15 and 45-16). Vertical incisions are made anterior and posterior to the crestal incision. The incisions are then followed through the lateral cortex using a saw (Figure 45-17). The sagittal bone cut along the crest is made as deep as possible, whereas vertical bone cuts extend to the lingual or palatal cortical plate. The bone flap is then freed slightly using an osteotome (Figure 45-18). A soft tissue flap is not raised. The device is tapped into the



FIGURE 45-15 Three incisions made through the mucosa and the periosteum.



FIGURE 45-18 The bone fragment is detached and freed slightly using a thin osteotome.

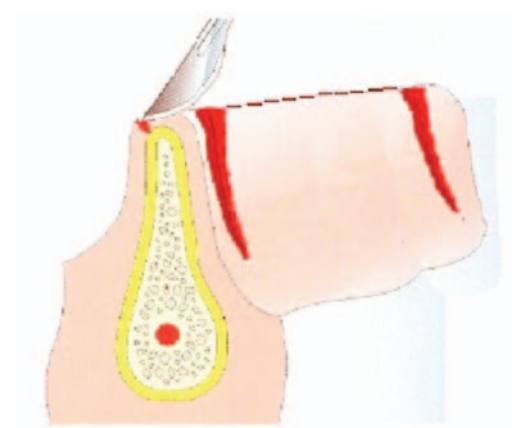


FIGURE 45-16 Illustration shows a horizontal incision lingually/palatally to the crestal peak.



FIGURE 45-19 The crest widener is tapped into the crestal cut.

crestal cut (Figure 45-19) and ligated with a titanium wire to an adjacent tooth. The device can also be inserted at a later date under local anesthesia. Activation of the distractor is done by the patient, half a turn, twice a day (0.8 mm

in total). In cases in which the cortical bone is very thin, a slower rate of half a turn a day is recommended (0.4 mm total).

The crestal sagittal bone cut has to be slightly lingual to the peak of the alveolar crest because

the crestal cortical bone is thicker and able to withstand the compressive forces of the distractor. A horizontal bone cut can also be made if needed to free up the transport segment by tunneling at the depth of the vestibule. This will allow the transported bone to be distracted with less force but adds the risk of devitalizing the segment.

Once sufficient width of the crest is achieved, activation is stopped. The distractor is removed under local anesthesia. The expanded ridge and soft tissue are left to heal for 10 to 14 days, during which some shrinkage is expected. Implants are then inserted. The implants wedge the crest apart and support the distracted buccal cortical plate, preventing relapse. The osseointegration period is still 3 to 4 months prior to dental restoration.

Figures 45-20 through 45-25 show a thin alveolar crest that was distracted to gain width. After 5 days of latency, the patient activated the device (Figure 45-26) at a rate of 0.8 mm per day (Figure 45-27). Eighteen days later, a gain of more than 5 mm in width was achieved (Figure 45-28). Twenty-eight days postoperatively, soft tissue healing was complete (Figure 45-29) and a computed tomographic scan was done (Figure 45-30).

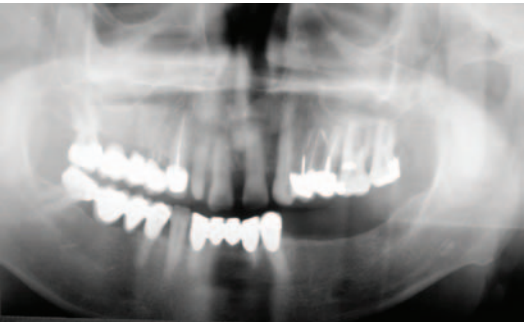


FIGURE 45-20 Preoperative panoramic radiograph showing sufficient crestal height.



FIGURE 45-21 Intraoral view; crestal width is insufficient for implantation.

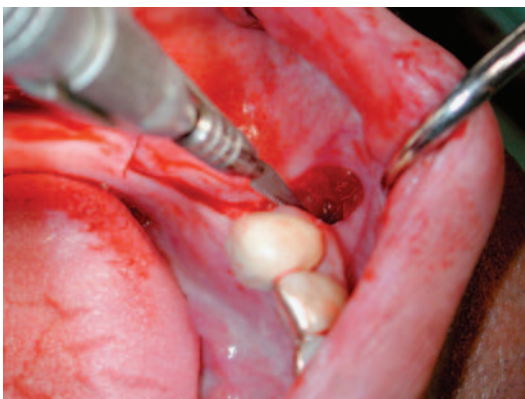


FIGURE 45-22 Bone cuts using a scalpel saw.



FIGURE 45-23 The crest widener is tapped into the bone cut.

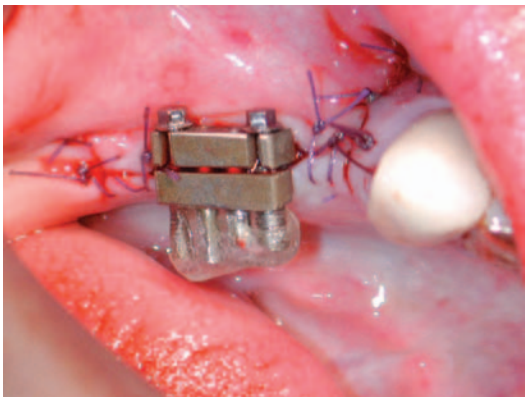


FIGURE 45-24 The screws and rods are cut and the sharp edges are covered with denture soft liner to prevent tongue irritation.



FIGURE 45-25 Postoperative panoramic radiograph.



FIGURE 45-26 Self-activation of the device.



FIGURE 45-27 Activation of the crest widener by the spanner.



FIGURE 45-28 Sufficient crestal width is achieved. The attached gingiva is also widened.



FIGURE 45-29 Complete healing of soft tissue after removal of the device.



FIGURE 45-30 Three-dimensional computed tomographic scan of the distracted crest.

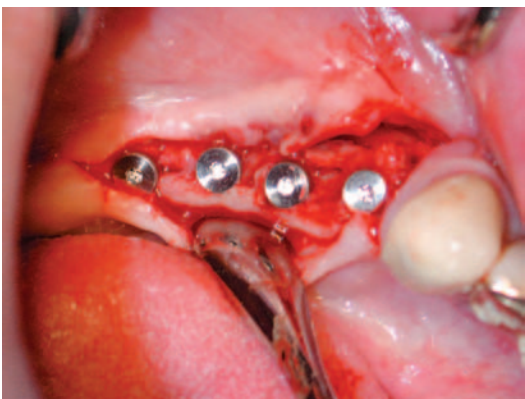


FIGURE 45-31 Implants inserted 28 days postoperatively.

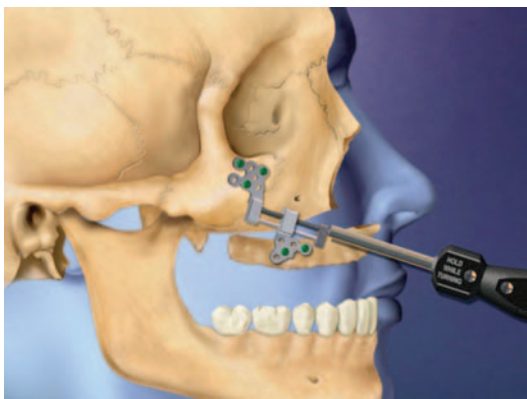


FIGURE 45-35 Schematic drawing showing the advanced maxillary position.

Implants were placed using a staged approach (Figure 45-31). On exposure of the widened ridge, osteoid is observed between the buccal and lingual plates. Three months postimplantation, final rehabilitation was performed (Figure 45-32).

In case 4, a 35-year-old female presented with an 18-year history of maxillary edentulism. She desired a natural-looking fixed prosthesis to replace her removable upper denture. The lower dentition was intact and in good condition. Figure 45-33 demonstrates a resorbed and atrophic maxilla. Figure 45-34 shows a schematic with distraction devices in place prior to movement of the entire maxilla anteriorly. For total jaw distraction, a rate of 1 mm a day is used. Figure 45-35 shows the maxilla in the advanced position. Figure 45-36 demonstrates the desired maxillary position, which was accomplished by bilateral horizontal distraction to advance the maxilla forward about 7 mm and down about 5 mm. Four months later, the maxillary soft tissues were sculpted to create pseudopapillae anteriorly (Figure 45-37), whereas eight implants were placed posteriorly. Figures 45-38 and 45-39 demonstrate the final fixed porcelain-bonded-to-metal restoration. The natural appearance derived for this relatively young patient could probably not be achieved without distraction osteogenesis.

These various distraction osteogenesis procedures reveal the underlying embryonic capacity lying dormant within the periosteal envelope. These devices reward the restoration-minded surgeon with yet another tool to regain orthoalveolar form on the way toward dentoalveolar restoration.



FIGURE 45-32 Final rehabilitation 4 months postoperatively.



FIGURE 45-36 Postdistraction view showing the desired maxillary position.



FIGURE 45-33 Preoperative view showing resorbed and atrophic maxilla.

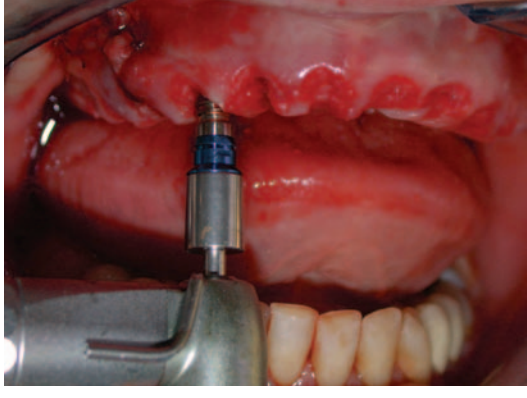


FIGURE 45-37 Maxillary soft tissues are sculpted and implants are placed 4 months postdistraction.

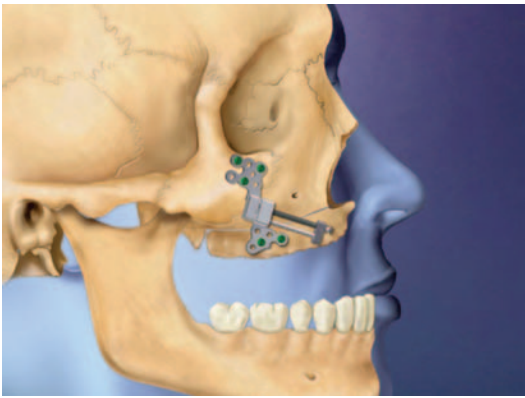


FIGURE 45-34 Schematic drawing showing distraction devices in place prior to activation.



FIGURE 45-38 Final fixed porcelain-bonded-to-metal restoration.



FIGURE 45-39 Final restoration, lateral view.

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Bone Transport by Distraction Osteogenesis for Maxillomandibular Reconstruction

César A. Guerrero, Marianela Gonzalez and Enif Dominguez

Mandibular reconstruction as a gold standard procedure requires bone graft, heavy rigid fixation armamentarium, and long hospitalization periods; and the final outcomes are still unpredictable secondary to many variables.

Patients treated by distraction osteogenesis bone transport present a better clinical condition, in terms of new bone and soft tissues with identical characteristics from the adjacent structures, as well as the quality and quantity of bone and mucosa ideal for osseointegrated implants for final esthetics and functional reconstruction, offering long-term treatment stability.

Mandibular Bone Transport

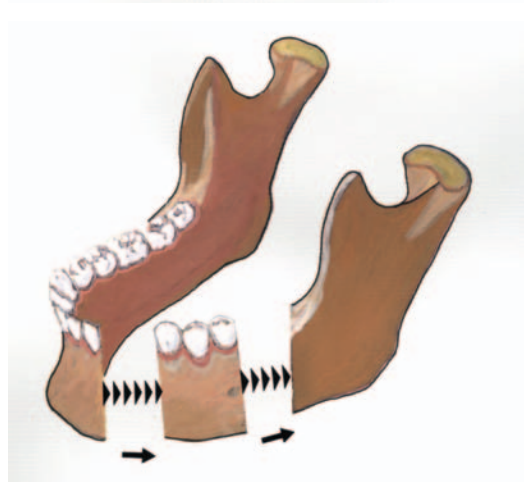
Systematic Description of the Three-Dimensional Problem

The bone transport technique involves creating bone and soft tissues to fill up a defect, at the expense of moving a disk of bone, and forming the new tissues behind its wake until the disk docks into the receiving host bone. Depending on the number of segments, these could be classified as bifocal (Figures 46-1 through 46-10), trifocal (Figures 46-11 through 46-14), tetrafocal, pentafofocal, etc.

Indications

This technique is the treatment of choice (1) in the case where patients are medically compromised and require surgery without major bone grafts, (2) as an alternative for re-intervention after an unsuccessful bone graft reconstruction, and (3) as a need to minimize costs to the expense of prolonged surgery and hospitalization. It is also indicated for the following circumstances:

- Following removal of benign tumors
- Reconstructing gunshot wound defects
- Managing osteomyelitis
- Treating malunions or nonunions



FIGURES 46-1 AND 46-2 Bifocal distraction.

Presurgical Preparation

Stereolithographic models and panoramic cephalometric x-rays are used for surgical planning and prediction. Stereolithography, in particular, is very useful for obtaining (1) large reconstructions and the anatomic model of the defect, with the exact measurements for pre-bending of the reconstruction plate, devices, and distraction vector; and (2) the location of the screws prior to surgery (Figures 46-15 and 46-16).

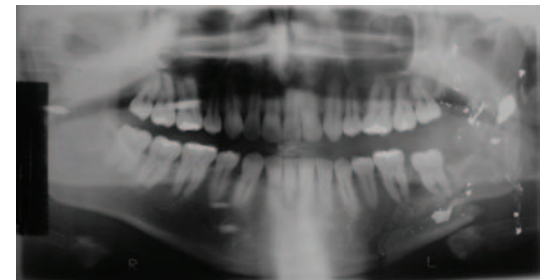


FIGURE 46-3 Panoramic radiograph of a patient with a gunshot wound to the mandible.



FIGURE 46-4 Patient previously treated by iliac crest bone graft, reconstruction plate, and platelet-rich plasma, with chronic infection, undergoing second surgical intervention to treat the problem using intraoral bone transport by distraction osteogenesis.



FIGURE 46-5 Intraoral distractor in place, wired to the teeth and screwed to the bone.



FIGURE 46-6 Distraction completed at a rate of 1 mm/day.



FIGURE 46-7 During the consolidation period, brakets, bands, and a spring were used to maintain the teeth between the segments in position.

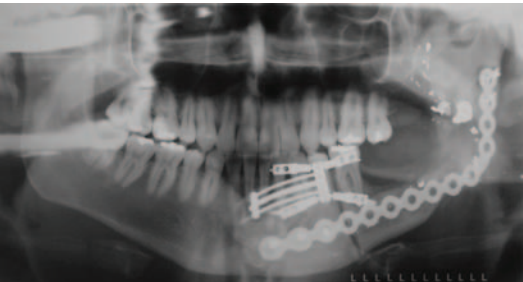


FIGURE 46-8 Distractor in place, to begin with bone transport.



FIGURE 46-9 End of distraction.

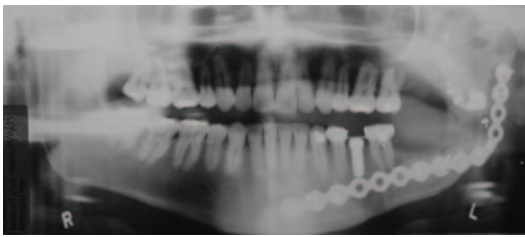
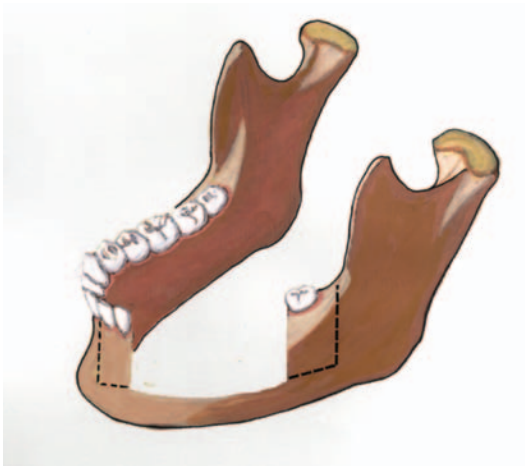


FIGURE 46-10 Dental implant, placed 3 months later into the mineralized distraction area.



FIGURES 46-11 AND 46-12 Surgical design of trifocal bone transport preserving the mandibular inferior border.



FIGURES 46-13 AND 46-14 Example of trifocal distraction with complete resection of the segment.



FIGURE 46-15 Three-dimensional reconstruction from a computed tomography scan of a patient with an ameloblastoma.

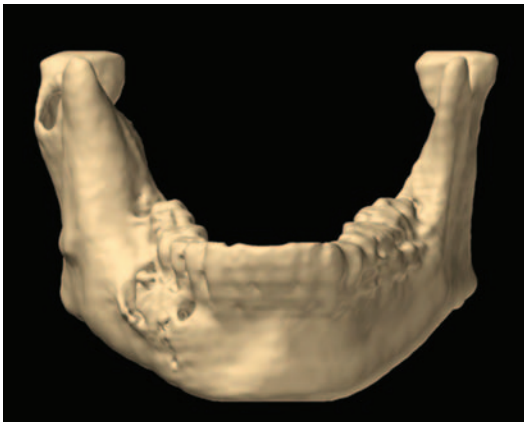


FIGURE 46-16 Stereolithographic model obtained from a computed tomography scan, to be used for surgical planning. (Design of the transport disk, bending of the reconstruction plate, distraction vector.)

Variables

Periosteal preservation should be considered as the most important biologic foundation.

- Amount of bone: The bigger the segment to produce new soft and hard tissues, the thickest the distracted final product will be.
- Quality of bone: The better the quality of bone (good cortical and bone marrow), the better the distraction regeneration will be.
- Degree of movement: The longer the distance to be transported by the disk, the bigger the segment needs to be.
- Precision in the surgical technique: The protocol needs to be followed for each individual indication. Abundant irrigation, small incisions, and periosteal preservation are mandatory for a successful distraction.
- Good soft tissue coverage: Watertight closure and transmucosal appliance placement are indicated to avoid infections, oral fluids filtration, or poor bone formation by disruption of the periosteum.

Biology of Distraction Osteogenesis in Bone Transport

Distraction osteogenesis is known as a process of bone formation between two osteotomized bone surfaces under tension-stress forces with a closed periosteum.

However, for major mandibular reconstructions, there are four topics of interest.

- A. When the defect includes the mandibular symphyseal curvature: Because the distraction will occur in a linear plane, from point A to point B, even though the plate follows the curvature for the symphyseal area, the distraction chamber will form bone in a straight line tending to go medially towards the tongue, away from the guiding reconstruction plate (Figure 46-17).

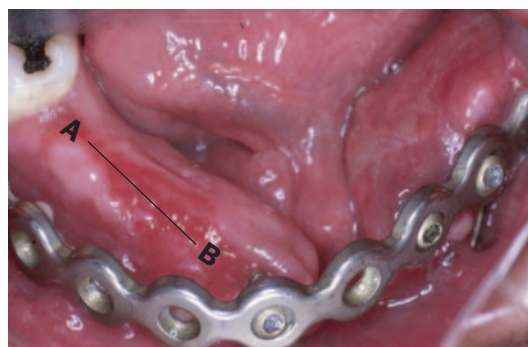


FIGURE 46-17 There is no possibility to create a curve with distraction, because the collagen fibers run from point A to point B.

- B. The size of the transport disk plays an important role in large reconstructions, especially when the symphysis is involved. The disk needs to be large enough for future sectioning in one or two segments as the bone travels along the defect, to comply with the distance needed for the reconstruction and to avoid the hour-glass deformity effect, and produce good quantity and quality of bone.
- C. The hour-glass deformity effect will be formed if a single bone disk needs to travel a long distance, or if the original thickness is not enough to recreate good bone. A segment of bone of a healthy mandibular body ranging from 1.5 to 2.0 cm in thickness, height, and length is necessary to form good new bone in the distraction area (Figure 46-18).
- D. The soft tissues will also advance along and recreate soft tissues with the bone being transported. The significance of this becomes very important in major reconstructions, because it includes all the musculature of the floor of the mouth. The biology of distraction applied to the muscles is still under analysis in animal research. To date, in orthopedics, the results have revealed that after 20% tibial lengthening at the rate of 0.75 mm/day, some muscles compensate myofiber length mainly by increasing the length of the existing sarcomeres, whereas other muscles gave indirect evidence of sarcomerogenesis.

Surgical Procedure, Osteotomy Design, and Device Orientation

General Concepts of Bifocal Distraction

Concept. Bifocal distraction is the use of one distraction disk to create new tissues for reconstructing the mucosa and bony defects. It is referred to as bifocal, based on the two zones that are present: the regenerate area and the docking-site area (Figures 46-19 and 46-20).

Surgical Principles

- Bifocal distraction is used to reconstruct small defects; it is up to the clinician's criteria to determine the size of the appliance and plate to be used for each individual case.

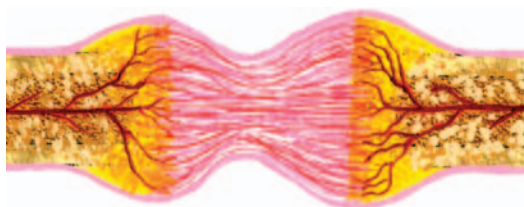


FIGURE 46-18 Hour-glass deformity effect, created after distraction when the collagen fibers have to stretch a long distance.



FIGURE 46-19 Panoramic radiograph of a patient with recurrent plexiform ameloblastoma.

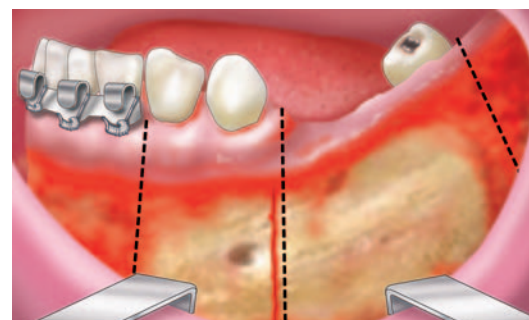
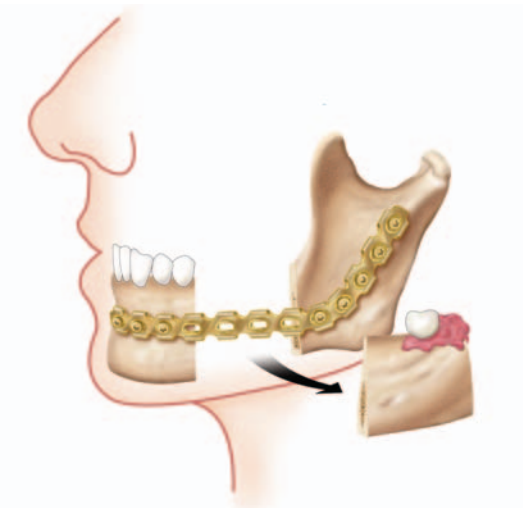
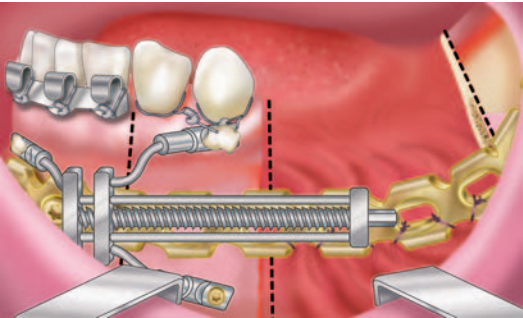


FIGURE 46-20 Surgical planning. The transport disk includes the premolars, and the posterior segment will be the bone to be resected.

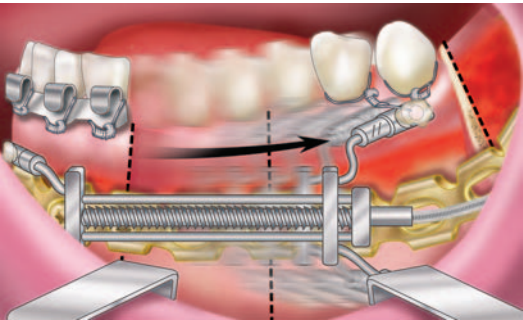
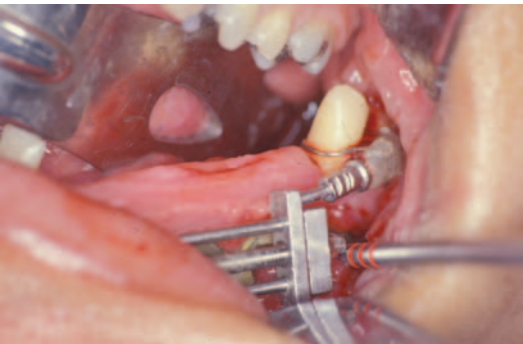
- It is performed in two surgical stages:
 - First surgical stage: Placement of the reconstruction plate, removal of the affected area, fixation of the distractor, and acute intraoperative activation of 2 mm (Figures 46-21 and 46-22); during the activation period, activation is 1 mm per day until the planned movement is achieved (Figures 46-23 through 46-27)
 - Second surgical stage: Rigid fixation of the transported bone to the reconstruction plate with bicortical screws, distractor removal, and docking-site surgery of the two hypotrophic docking bone segments (see Figure 46-27)
- The consolidation period is based on previous histologic research studies. For each centimeter of distraction, 60 days of consolidation are required. The panoramic and periapical radiographs are very useful to visualize bone formation and mineralization.
- After the consolidation period has elapsed, either the screws are removed from the plate and dental implants placed for prosthetic reconstruction; or the plate can be completely removed if the segments have good mineralization and consolidation (Figures 46-28 through 46-33)

General Concepts in Pentafoveal Distraction

The technique is performed as an ambulatory surgical procedure. Intraoral distraction



FIGURES 46-21 AND 46-22 Diagram demonstrating the intraoral placement of the reconstruction plate to guide the distraction and to maintain the mandibular segments in place. The distractor and the disk travel over the reconstruction plate.



FIGURES 46-23 AND 46-24 The disk traveling to meet the docking site.



FIGURE 46-25 End of distraction, and beginning of the mineralization period. The armamentarium is kept in place to maintain stability of the segments until complete mineralization is achieved (60 days of stabilization for each centimeter of distraction).

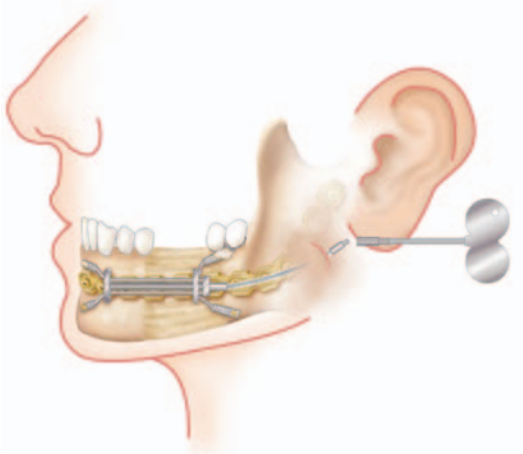


FIGURE 46-26 Intraoral distraction by bone transport with extraoral activation. A minimal incision is made through the skin to maintain the activation key available during the active phase of distraction; once the distraction is completed, the key is removed.

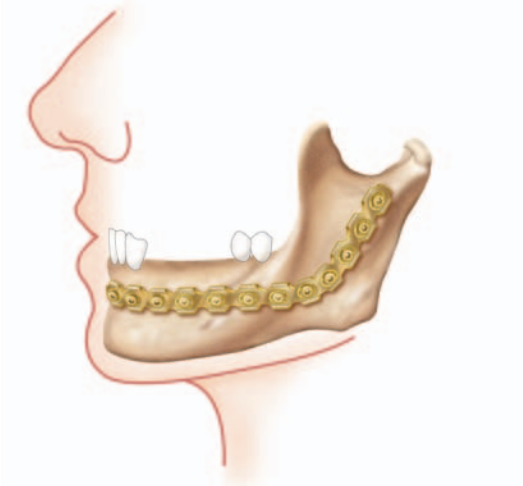


FIGURE 46-27 Removal of the distractor 2 months after completion of distraction, and rigid fixation with bicortical screws of the new bone during the mineralization period.

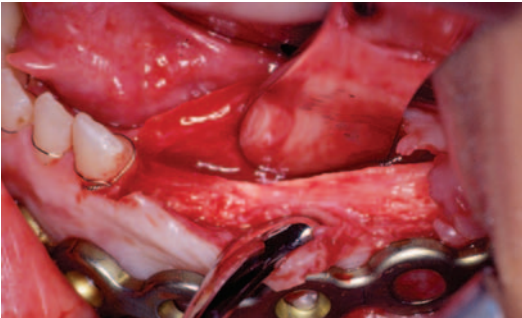


FIGURE 46-28 The new bone after 60 days of consolidation, ready for dental implants.

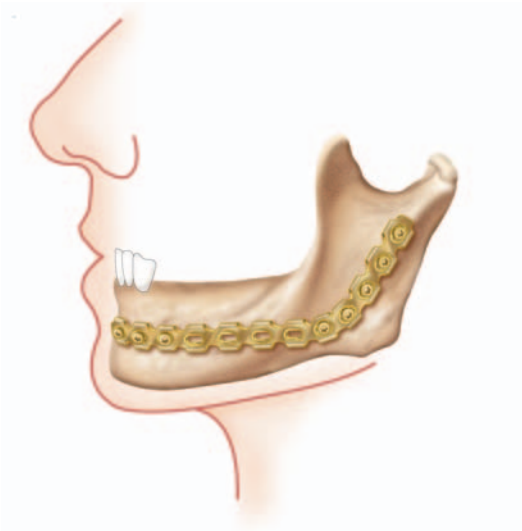


FIGURE 46-29 If necessary, the screws are removed to allow implant placement.

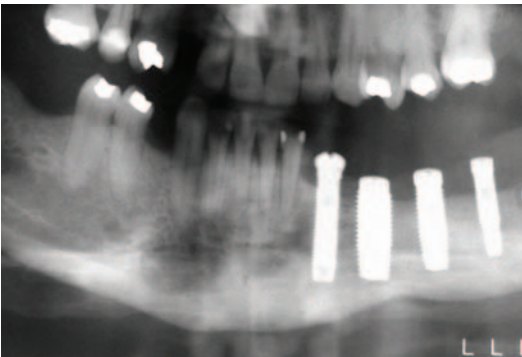


FIGURE 46-30 Panoramic radiograph with 4 dental implants in the bone newly formed by distraction.



FIGURE 46-31 The final prosthetic restoration.

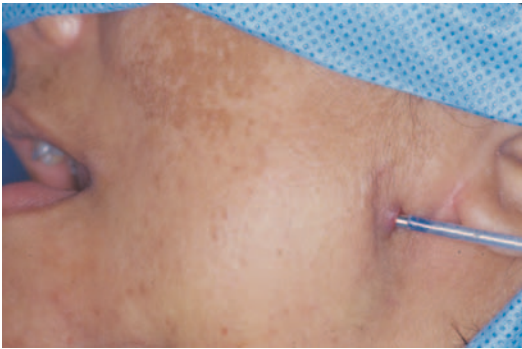


FIGURE 46-32 Facial view, demonstrating the activation.



FIGURE 46-33 Lateral facial view at the end of the intraoral distraction treatment, with no facial scars.

osteogenesis is always the method of choice. Once the reconstruction plate is perfectly adapted and fixed to the two proximal segments to avoid segment displacement, the tumor is resected and the transport disks are osteotomized in a sagittal orientation half way up, from the inferior border of the mandible, without completing the osteotomy (Figures 46-34 and 46-35).

The distractors are freely placed on either side, over the reconstruction plate, and fixed to the bone with bicortical screws. For large movements, the transport disks should be as large as possible (ranging from 6 to 8 cm) in order to plan the future splitting of the same disk. The osteotomy is then completed by the use of a mallet and an osteotome. The distractors are activated 2 mm intraoperatively to verify the completion of the osteotomy (Figures 46-36 through 46-39).



FIGURE 46-34 Patient with a plexiform ameloblastoma.



FIGURE 46-35 The tumor is resected after the reconstruction plate is fixed.

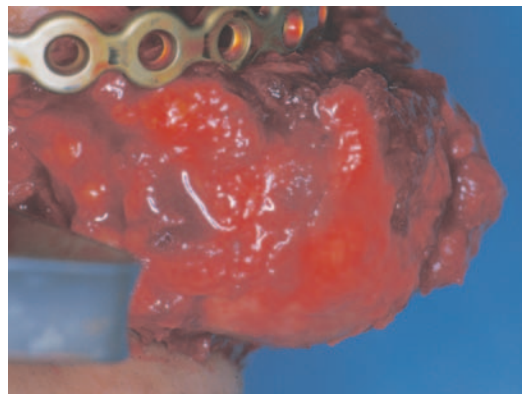


FIGURE 46-36 The lesion is remodeled if the size of the tumor interferes with the placement of the plate.

All the musculature and soft tissues around the floor of the mouth are repositioned and sutured to the reconstruction plate with 3-0 Vycril suture (Figures 46-40 through 46-42).

After surgery, a 7-day latency period is provided, followed by a 0.5 mm twice-daily activation phase, until the desired distraction is achieved (Figures 46-43 and 46-44). Once the transported



FIGURE 46-37 One distractor on either side to transport the disks forward. Note the use of activation key extenders to the symphyseal area.



FIGURE 46-38 Design of the distraction disk on the right side.



FIGURE 46-39 Design of the distraction disk on the left side.



FIGURE 46-40 Suture of the musculature of the floor of the mouth to the reconstruction plate at the symphysis.

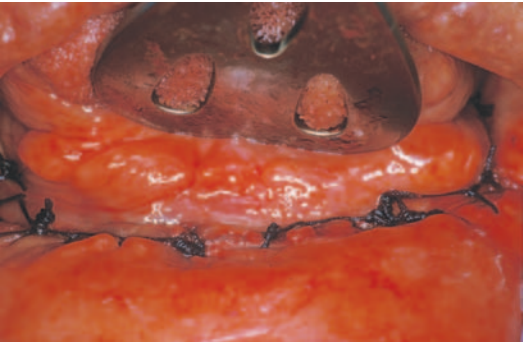


FIGURE 46-41 On a second plane, the mucosa is also sutured to the plate.

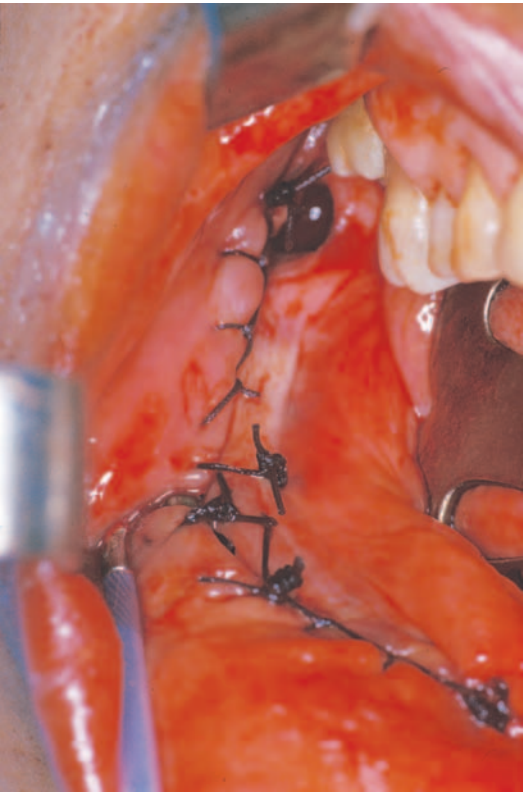


FIGURE 46-42 Suture of the distraction area, with the activation extensor exposed to the oral cavity.



FIGURE 46-43 Radiograph during distraction.

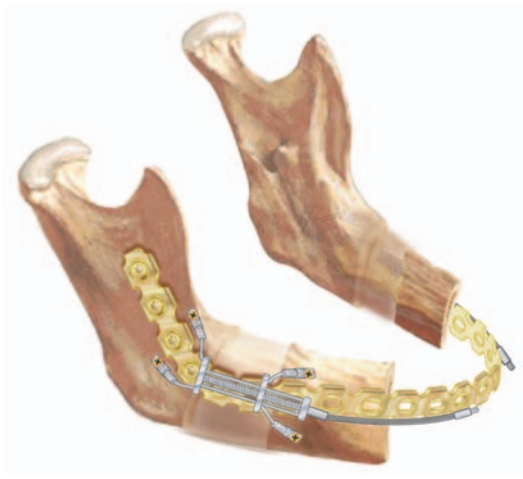


FIGURE 46-44 Diagram to demonstrate the movement of the two discs.

disks or bullets have reached the symphyseal area, under intravenous sedation, the major disk is divided in two (Figures 46-45 and 46-46).

The posterior half is fixed to the reconstruction plate with 2.7 mm bicortical screws, and a new distraction device is placed transversally in the second half, to travel from canine to canine area (see Figures 46-45 and 46-46).

Once the bony segments meet, a docking-site surgery is performed to unite the two segments. All the transported disks are fixed in place to the reconstruction plate with 2.7 mm screws (Figures 46-47 and 46-48).



FIGURES 46-45 AND 46-46 The bigger disk is divided in two. The posterior segment is fixed to the plate and the anterior will continue traveling toward the symphysis.



FIGURES 46-47 AND 46-48 During mineralization, the distractors are removed and the distracted segments fixed to the plate.

Figures 46-49 through 46-53 show the complete mandibular reconstruction from second molar to second molar with intraoral distraction without extraoral incisions.

Summary for Pentafoveal Distraction

Concept. The technical concept is based on the use of as many bone disks as are needed for the



FIGURES 46-49 AND 46-50 Three years later. Dental implants and hybrid prosthetic reconstruction placed into the new mandible.



FIGURE 46-51 Preoperative frontal view.

distraction to repair the defect, and rigid fixation to maintain stabilization of the segments in place.

Principles

- The reconstruction plate needs to be placed following the principles of reconstruction.



FIGURES 46-52 Postoperative frontal and lateral views, without extraoral scars.

It should be stable, holding the bones in the correct position, with at least 3 bicortical screws on each segment.

- For defects including the body and half or all of the symphyseal area, a complete side-to-side reconstruction plate is indicated.
- The appliance travels on top of the plate for vector control, and it is placed supraperiosteally in order to prevent violation of the biologic principles of distraction osteogenesis of periosteal nutrition to the area.
- These major angle-to-angle reconstructions are performed by stages.
 - First stage: Tumor resection of affected bone, placement of reconstruction plate and distractor with transport disk design, and 2 mm intraoperative activation. This first disk is usually from the angle of the mandible or from the most posterior part of the body, at least 4 cm in length; this segment will travel up to the canine area.
 - Second stage: Reconstruction of the symphysis. Once the first disk reaches the canine area, intravenous sedation is planned to section this disk in half so as to design a new disk. Rigid fixation of the posterior portion of the original disk to the reconstruction plate is accomplished and the distractor is removed. The anterior portion of this disk will continue traveling to go across the symphysis with a new distractor. It is very important to consider as a rule the rigid fixation of the already transported disk to the plate, to avoid the spring effect (contraction of the collagen fibers trying to pull back the segment to its original position) when the mineralization period has not been achieved. The consolidation period for major movements is prolonged for many months.
 - Third stage: At the end of the distraction, docking-site surgery is indicated to promote healing between the two docking segments. This is a short and simple procedure to be done under intravenous sedation.

Intraoperative Considerations

If a complete osteotomy has been accidentally performed before the fixation of the appliance, it is necessary to place a temporary miniplate to maintain the segments in position until the distractor is completely fixed to the bone. After that, the miniplate should be removed (Figure 46-54).

Distraction Protocol

The protocol involves 7 days of latency period (no activation), followed by a 1 mm activation once a day, until distraction is completed (the

activation will be performed by the patient, family member, or office staff). The distractors remain in place for 2 months per each centimeter during the consolidation period as a fixation system, until they are exchanged for bicortical screws from the reconstruction plate to the bone.

Consolidation Period

The consolidation starts at the end of the distraction and it is followed by radiographs and established based on previous histologic studies. This period is usually 60 days for each centimeter of distraction. Severe soft tissue edema is evidenced after surgery, diminishing towards the third month after surgery, once the distractors are removed. A second phase of soft tissue shrinkage is also evidenced for a period covering up to the following sixth months. Finally, a progressive decrease is seen until the eighteenth month after surgery, with continuous bone and soft tissue changes.

Docking-Site Surgery

The docking site is the area where the two bone segments meet. At the end of treatment, the edges of these two bones are usually hypotrophic and sclerotic, covered by mucosa as a result of lack of irrigation. To close this gap at the end of the distraction, a docking-site surgery needs to be performed. For this technique, the two edges should be as close as possible and the nonvital bone needs to be removed.

A mucoperiosteal incision with minimal periosteal elevation is used to expose both ends; it is necessary to obtain a network of neoangiogenesis from the bone marrow and periosteum to enhance healing and promote better bone consolidation. The bone edges are prepared by making multiple perforations with a No. 701 bur into the cortical and medullary bone; the distractor is activated until the two segments closely meet, and the bone graft obtained either from the chin, tuberosity, or bone tramp is placed over the joining bones, possibly combined with additional osteoinductive material (eg, recombinant human bone morphogenetic protein 2; rhBMP2). Rigid fixation is used to keep the two bone segments united, either by the reconstruction plate or by two miniplates, depending on the bone stability and amount of reconstruction. Different soft tissue flap designs could be used; that is, sliding or three-dimensional advancing flaps, to properly cover the docking site area without tension, especially after the placement of bone grafts. The suture is protected with N-2-butylcyanoacrylate to isolate the surgical site from the oral bacteria.

Remodeling Period

The remodeling period starts with full functional muscle load after the distractors have been removed and continuous shrinkage has been



FIGURE 46-53 Postoperative lateral view showing no extraoral scars. Genioplasty augmentation with a prosthesis.

observed up to 18 months after surgery. Considering that minimal tissue damage was caused during surgery, the appliances would be fixed transmucosally and very limited periosteal stripping accomplished; still, some hard and soft tissue changes have been observed in a long-term follow-up.

Office Care

The patients can perform their own activation after they have seen and practiced it under supervision. They are followed on a weekly base for 3 months, and then every 30 days until completion of the treatment. Photographs, and panoramic, lateral cephalic, and posterior–anterior radiographs are used for consolidation and distraction vector follow-up, immediately after surgery and once a month for the first 3 months. A year later, dental implants are placed to complete dental rehabilitation.

Nutrition

These patients will require an adequate diet, considering the degree of mandibular resection. If the patient has enough dentition remaining, we prescribe a liquid diet (mechanical processed diet) for the first 4 weeks, including high-protein supplements, following by a soft diet for the following 8 weeks. When there is a major resection from side to side, the patient does not have the proper dentition for a normal function and will not be able to wear an implant. In this case, a liquid and a soft diet are indicated for the overall



FIGURE 46-54 Temporary miniplate to maintain the segments in position.

treatment until the appliances are removed and implants are placed to support an adequate prosthesis.

Masticatory Muscle Function and TMJ

On account of the fact that the patient can be on a soft and liquid diet, for a long period of time, the masticatory function is diminished. This can lead to a hypomobility of the masticatory muscles and TMJ, with the consequences of interincisal opening reduction at the end of the treatment. To avoid this, the patient needs to start functional and physiologic exercises three times a day for 15 minutes, to simulate masticatory movements. This physiotherapy must be carefully followed up by the clinicians.

Family and Patient Cooperation

Owing to the appliances available in the market and the reality of a long-term treatment period following the biologic principles of distraction, patients go through long follow-ups and treatment. They need to be actively cooperative and become very familiar with the technique and the results. It is a time- and technique-sensitive treatment that requires the patients to follow instructions carefully in order to obtain successful results.

Postoperative Considerations

For each centimeter of distraction, there should be 60 days of consolidation. Defects of the mandibular body, including the symphysis

(13 cm of missing bone), is considered a large reconstruction, despite that for orthopedic surgery, large treatments cover approximately 10 cm of bone defects. After the distraction is completed, the consolidation period is followed by periodic x-rays at every 2 months, which can account for a total of 18 months. If it is necessary, the reconstruction plate can be removed after a year to place the dental fixtures, which need to be reconstructed immediately with a bar.

Maxillary Bone Transport

Systematic Description of the Problem

The intraoral devices are ideal means to treat maxillary deficiencies in a two- or three-dimensional manner. In specific situations where there is lack of hard and soft tissues, different distraction osteogenesis techniques can be combined to solve deficiencies for trauma or for syndromes. This surgical approach eliminates the need for bone grafts or extraoral devices. Selecting the adequate surgical timing avoids permanent surgical damage to the teeth, nerves, and lachrymal ducts.

Indications

Indications for maxillary bone transport include the following:

- A. Tumor resection
- B. Trauma
- C. Midface deficiency
- D. Midface deficiency with velopharyngeal incompetence
- E. Velopharyngeal incompetence

Classification

- Bifocal distraction after tumor resection: a clinical case is illustrated in Figures 46-55 through 46-66).
- Trifocal distraction for trauma defect: a clinical case of a patient involved in a motor vehicle collision with traumatism to the anterior maxilla is illustrated in Figures 46-67 through 46-71.

A reconstruction plate is fixed to the teeth using interdental wires and screws, wherever possible, and acrylic to serve as a guide in the bone transport movement, reconstructing the maxilla to a normal shape. A small incision is made at the depth of the vestibule through the mucosa, muscles, and periosteum. The flap is elevated and small retractors are used to expose the bone adequately in a tunnel fashion. The transport disk is designed for each specific case, either bifocal or three-focal. The interdental osteotomy is performed under abundant irrigation to avoid bone overheating. The osteotomy is completed with a spatula osteotome, and the flap is carefully



FIGURE 46-55 Patient with previous hemimaxillomalar tumor resection; the oral cavity is communicated with the orbit.



FIGURE 46-56 Initial closure with palatal and tongue flaps.

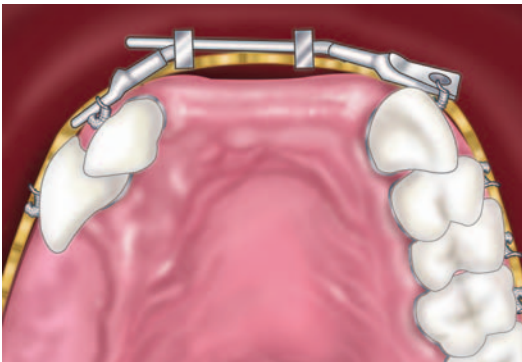


FIGURE 46-57 The distracted disk includes the lateral and central incisor from the left side. The distractor moves the segment to the right.

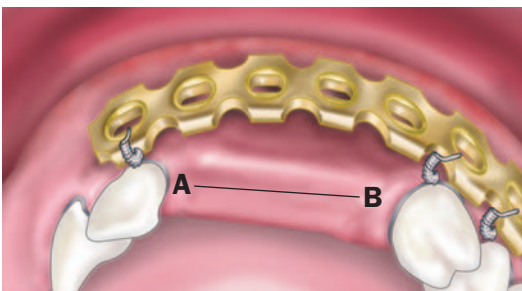


FIGURE 46-58 End of distraction. The collagen fibers ran from point A to point B; observe the separation between the plate and the tissues.



FIGURE 46-59 Panoramic radiograph during distraction.

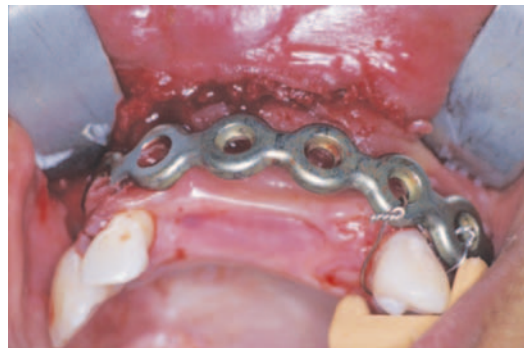


FIGURE 46-60 Clinical view at the end of distraction.



FIGURES 46-62 AND 46-63 Placement of dental implants 3 months later.



FIGURE 46-64 Prosthetic reconstruction 3 months after implant placement.



FIGURE 46-61 Preoperative facial view.



FIGURE 46-65 Preoperative facial view after maxillary reconstruction by bone transport distraction osteogenesis, temporal parietal bone graft and flaps for orbito-malar reconstruction.

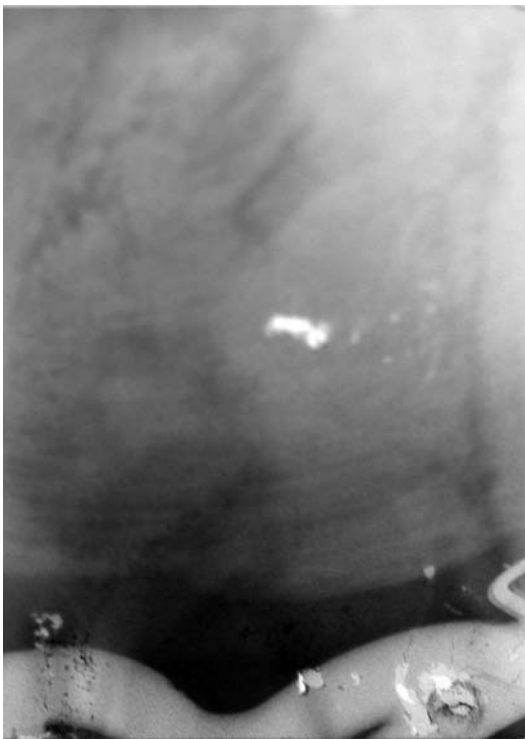


FIGURE 46-66 Periapical radiograph showing the fibrous interzone during the mineralization phase.

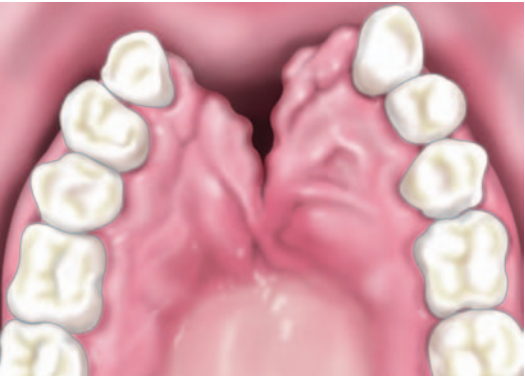


FIGURE 46-67 Defect of premaxilla with oronasal communication.

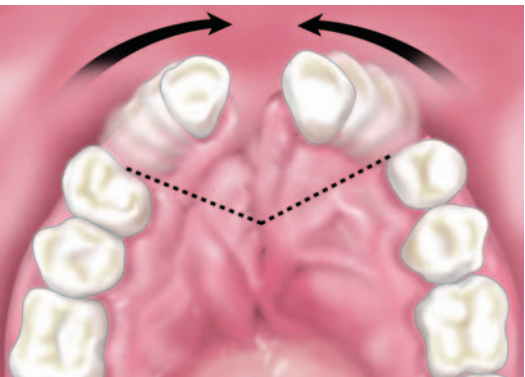


FIGURE 46-68 Osteotomy planning to reconstruct the defect by bone transport.



FIGURE 46-69 The appliance fixed to the two disks, to produce the movement toward the midline.

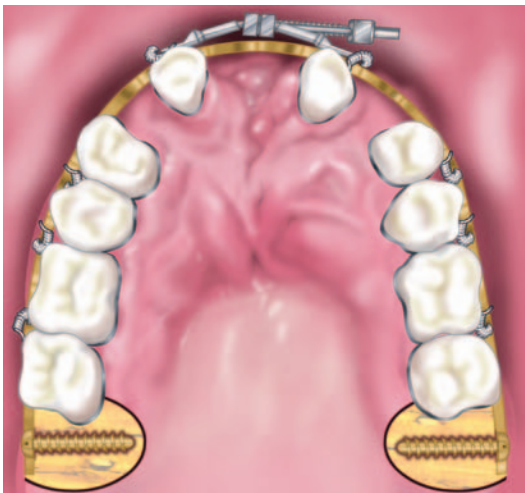
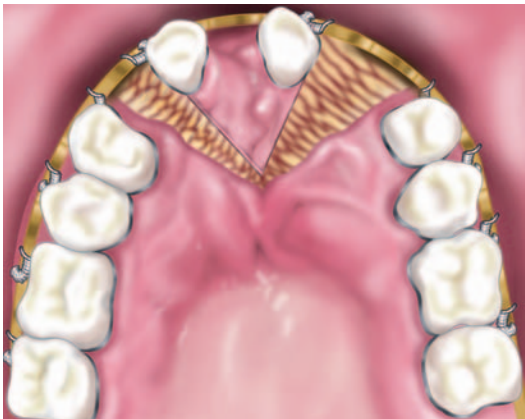


FIGURE 46-70 Diagram showing the reconstruction plate fixed to the maxilla with interdental wires and screws at the tuberosity.



FIGURES 46-71 Fixation of the two disks at the end of distraction, and removal of the distractor.

closed to enhance endosteal healing. The distractor is fixed over the reconstruction plate to the distraction disk and to the fixed maxilla with 2 mm positional screws and interdental wires.

The trifocal distraction surgical clinical sequence is illustrated in Figures 46-72 through 46-77.



FIGURE 46-72 Clinical photograph of a patient after a MVC. Oronasal communication, missing the premaxilla and incisors.



FIGURE 46-73 Panoramic radiograph during distraction, moving the canines toward the midline.

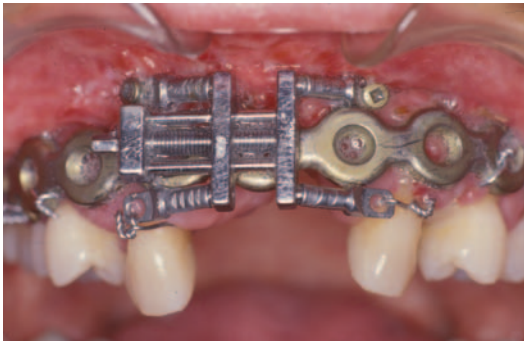


FIGURE 46-74 Clinical view during distraction.



FIGURE 46-75 Frontal view after treatment.



FIGURE 46-76 Occlusal view before treatment.



FIGURE 46-77 Occlusal view after treatment.

Distraction Protocol

Latency period of 7 days, followed by activation of 0.5 mm every 12 hours (0.5 mm twice a day) until the two bony segments meet, or until the segment has arrived to the final distraction point.

Docking-Site Surgery

Once the two segments dock with each other, a second procedure is required for uniting the two segments. This technique involves removing the epithelial tissue between the two segments and removing the hypotrophic bone edges from each disk. Perforations with a No. 701 bur into the cortical bony edges are used for bone marrow refreshing, and the two segments are approximated in good contact by activating the distractor. The two segments are fixed with low-profile microplates, and the reconstruction plate and distractor are removed. Different soft tissue flap designs can be used to complete the palate or alveolar closure.

After the consolidation period has elapsed (2 to 4 months for each centimeter, according to the follow-up panoramic and periapical radiographs), dental implants can be placed for fixed prosthetic reconstruction.

Technical and Biologic Considerations

1. The distractor should be firmly fixed to the distraction disk and the maxilla, to prevent

excessive movement of the distraction disk and fibrosis or cartilaginous healing.

2. The ideal minimal micromotion recommended for distraction healing is achieved by using as the smallest possible distractor arms, to decrease the overall distractor distance.
3. The device should be fixed to the basal bone and, at the teeth level, with interdental wires covered with resin to increase the rigidity.
4. Owing to the fact that the maxillary bone is usually not very thick, its ability to create new bone by distraction is reduced. That is the reason why the distraction rate is 0.5 mm twice daily and a docking-site surgery is mandatory.

Midface Deficiency

Description of the Problem

Severe maxillomalar deficiencies have been treated by conventional craniofacial and maxillofacial surgeries, with some limitations. Relapse, instability, bone grafts, maxillary advancements with poor bony interfaces, extensive rigid fixation, extended recovery, and treatment cost are some of the restrictions involved. Distraction osteogenesis offers the possibility to advance progressively the midface, control of the movement during the postsurgical period, intraoral approaches, and major advancements without the relapse. The combination of surgery and orthodontics is fundamental to ideally correct the three-dimensional problems. The surgical plan is based on a stereolithographic model for distraction vector control.

Surgical Technique

High Le Fort I or modified Le Fort III is used to advance the midface. For the modification of the Le Fort III, an additional transconjunctival approach is used. The osteotomy divides the malar process, carried out medially and above the infraorbital nerve. The orbital floor is sectioned behind the infraorbital rim, continuously underneath and obliquely anterior to avoid the nasolacrimal duct from reaching the piriform rim, and posteriorly extended to the pterygomaxillary suture. Two wide-curved osteotomies are placed behind the maxillary tuberosities to displace the malar-maxillary complex. The posterior arms of the distractors are fixed to the malar bone, and the two anterior arms are wired to the teeth or fixed with screws transmucosally, depending on the osteotomy level. For those cases where the appliance is buried under the mucosa, a flexible connector is attached to the distractor activation head to facilitate activation (Figures 46-78 and 46-79).

Distraction Protocol

Latency period of 7 days, followed by activation of 1 mm a day, until distraction is completed as



FIGURE 46-78 High Le Fort I design.

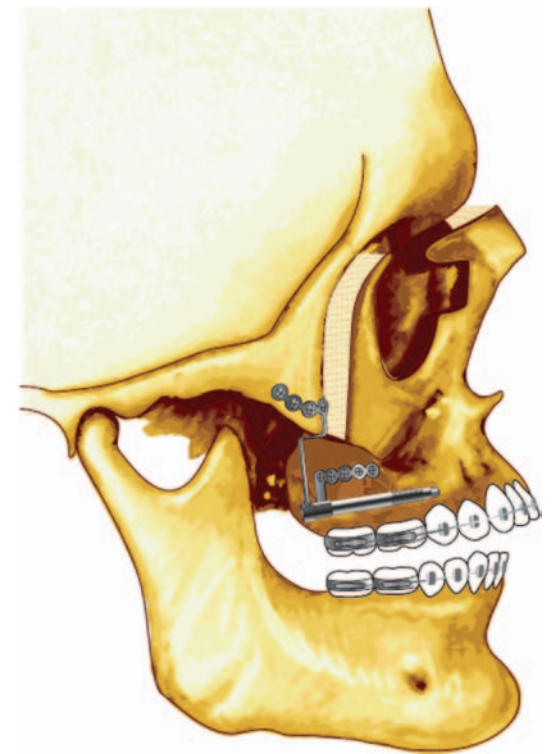


FIGURE 46-79 Le Fort III design.

planned in the prediction. Consolidation is 60 to 90 days per each centimeter distracted.

Consolidation

One way of checking for consolidation at 60 days of the midfacial distraction is by removing the fixation of the anterior arms of the distractor, with attempts to move the maxilla. If some mobility is observed, attributed to poor thickness of the original bone to form new good bone, then another 30 days of consolidation should be added.

Figures 46-80 through 46-91 illustrate a clinical case of high Le Fort I for maxillary



FIGURE 46-80 Preoperative view of a patient with a facial asymmetry and maxillary hypoplasia.



FIGURE 46-81 Preoperative facial view.



FIGURE 46-82 Preoperative dental lateral view.



FIGURE 46-83 Occlusion after completion of distraction.



FIGURE 46-84 Lateral dental view after treatment.

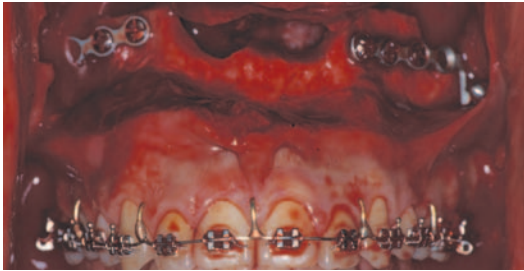


FIGURE 46-85 The distractors fixed in place paralleled to each other, following the mandibular occlusal plane to produce a distraction vector adequate to avoid an open bite.



FIGURE 46-86 Immediate posteroanterior radiograph.

distraction combined with conventional osteotomies. A clinical case of Le Fort III for maxillary distraction is illustrated in Figures 46-92 through 46-95.

The distraction vector is guided by the distractor placement, to avoid malocclusion at the end of treatment; the distractor should be placed to follow the occlusal plane, and in considering the vertical relationship in maxillary vertical excess or deficiency (Figures 46-96 through 46-106).

Midface Deficiency and Velopharyngeal Incompetence

Description of the Problem

Patients with cleft palate usually require maxillo-mandibular osteotomies to correct their Class III deformities. They also frequently present with

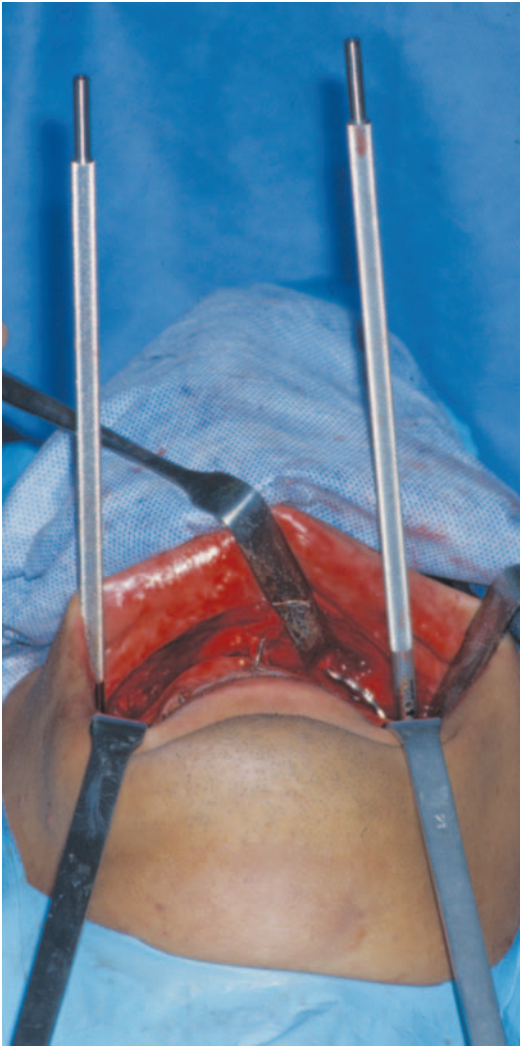


FIGURE 46-87 Intraoperative examination of the distraction vector. Temporary bars are used to check the parallelism.

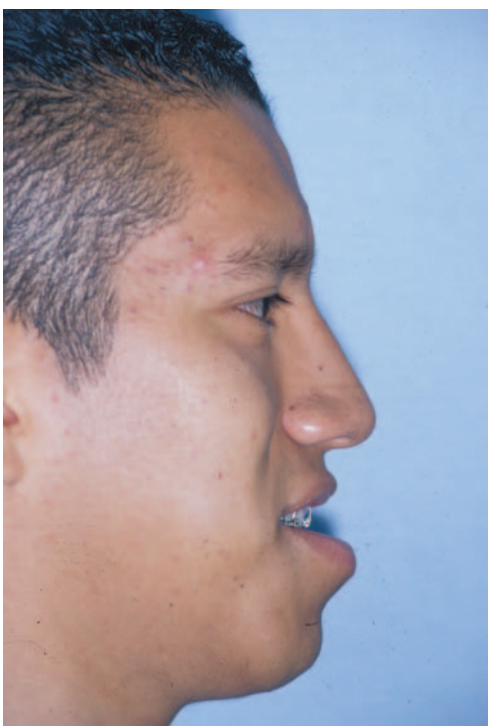


FIGURE 46-88 Preoperative lateral facial view.

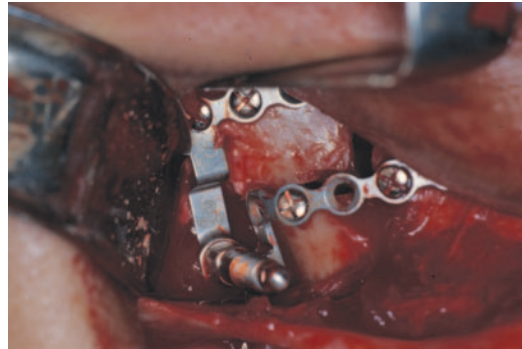


FIGURE 46-89 High Le Fort I osteotomy and distractor placement. The distractor's plates are fixed to the bone and covered by the mucosa; the activation screw remains outside the periosteal envelope.



FIGURE 46-90 Postoperative lateral facial view.

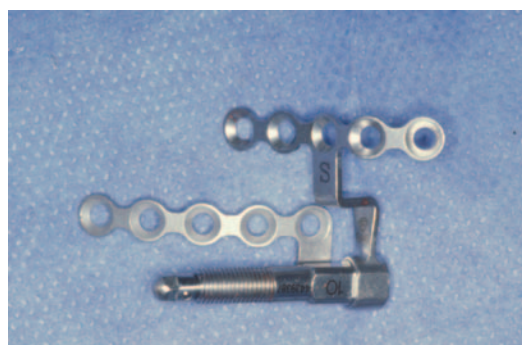


FIGURE 46-91 The maxillary distractor.



FIGURE 46-92 Preoperative lateral cephalic radiograph showing anteroposterior and vertical maxillary deficiency in a Cruzon syndrome.



FIGURE 46-93 Lateral cephalic radiograph after maxillary advancement by distraction.

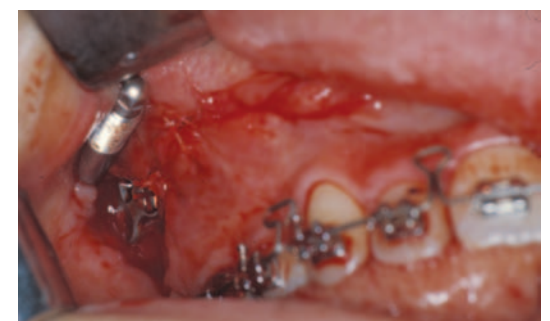


FIGURE 46-94 Intraoral emergence of the distraction rod.



FIGURE 46-95 Frontal dental view, before treatment.

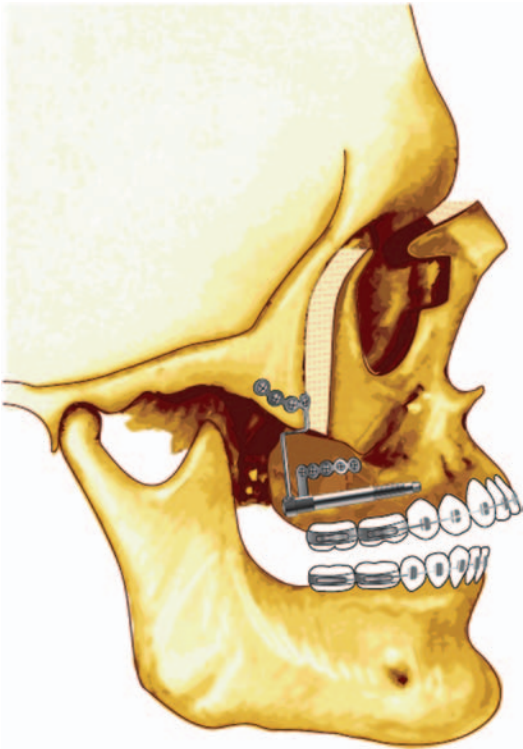
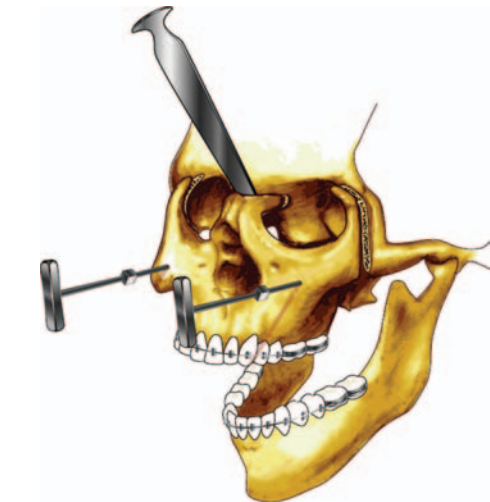


FIGURE 46-98 Distractor placement simulating the movement. The parallelism and distraction vector of the activation screw should be considered with the occlusal plane, to avoid malocclusions at the end of treatment.



FIGURE 46-100 Frontal dental view after maxillary distraction osteogenesis.



FIGURES 46-96 AND 46-97 Diagram demonstrating the Le Fort III osteotomy for midface advancement, and the use of two Carroll-Girard screws or the Norman Rowe desimpaction forceps to facilitate the midface disjunction.



FIGURE 46-99 Alignment rods to verify parallelism.



FIGURES 46-101 AND 46-102 Transconjunctival approach combined with transcutaneous nasal osteotomy, to complete the midface osteotomies without extraoral facial scars.



FIGURE 46-103 Postoperative lateral view of a patient with Cruzon syndrome.



FIGURE 46-105 Postoperative lateral facial view.



FIGURE 46-104 Preoperative frontal view.

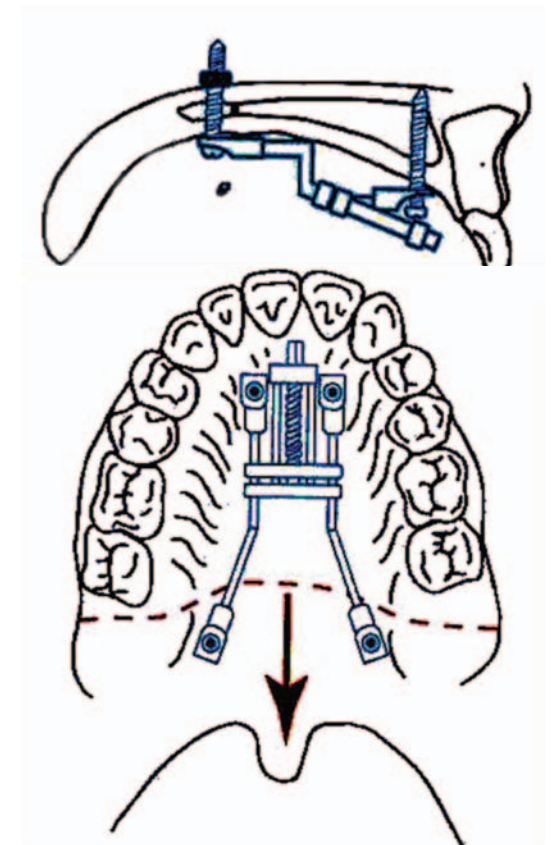


FIGURE 46-106 Postoperative frontal view after Le Fort III advancement by distraction osteogenesis, genioplasty, and rhinoplasty.

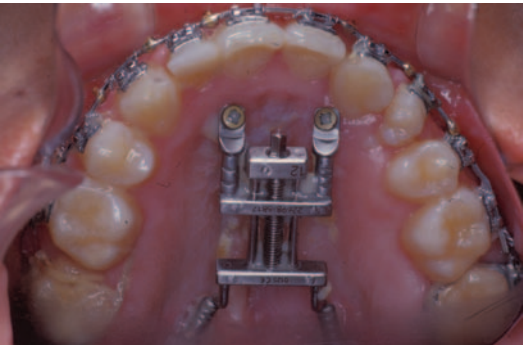
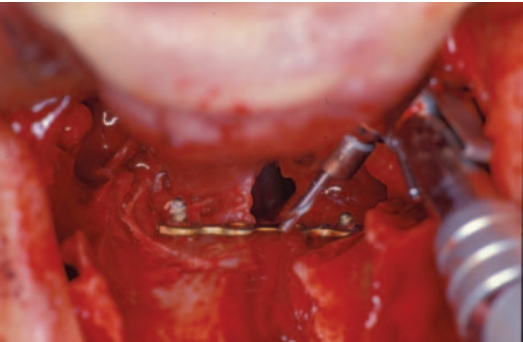
borderline velopharyngeal incompetence, developed after multiple surgeries. Simultaneous acute maxillary advancement, combined with posterior palate repositioning by distraction osteogenesis in one surgical stage, is used to advance the maxillomalar complex and to prevent progression or correct velopharyngeal incompetence (Figures 46-107 through 46-114).

Surgical Technique

Traditional maxillary advancement by high Le Fort I osteotomy is performed in a standard fashion. After the down fracture has been completed, a horizontal osteotomy of the palatine bones at the maxillary junction is carried out. Using this portal, a miniplate is used to fix the two palatine bones as one unit to the posterior arms of the distractor in place, with the screws and the distractor from the palate to the nasal floor. The other two screws are placed all the way through the plate, from the nasal floor through the palate, with a dental implant handpiece. The two anterior arms of the distractor are also fixed with screws to the anterior maxilla. The distractor is activated 2 mm intraoperatively to check appliance activation. The Le Fort I is positioned, as planned in the prediction, and fixed in a standard fashion with



FIGURES 46-107 AND 46-108 Cephalometric schematic representation of distractor placement. Occlusal posterior palatal repositioning during the distraction movement. For velopharyngeal incompetence in simultaneous maxillary Le Fort I advancement.



FIGURES 46-109 AND 46-110 Placement of the miniplate to unite the two palatine bones. The other two screws are placed through the plate from the palate to the nasal floor, and the anterior arms are fixed to the anterior maxilla.

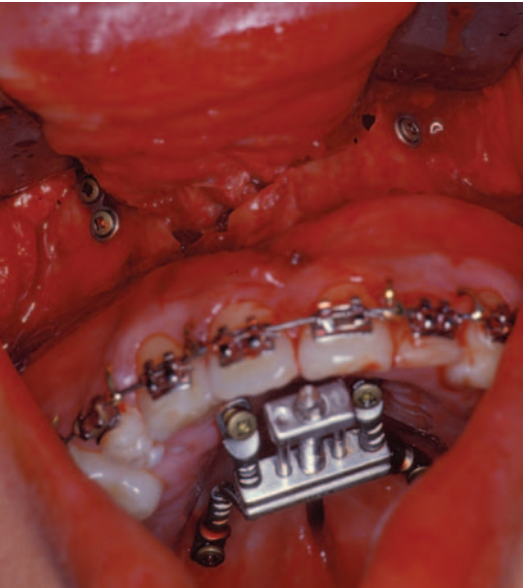


FIGURE 46-111 Intraoperative fixation of high Le Fort I osteotomy by the conventional orthognathic procedure combined with posterior distraction of the palate.



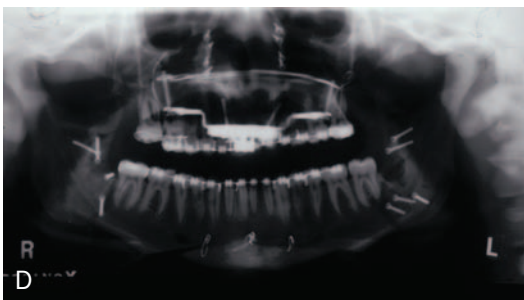
(A) Preoperative



(B) Immediate after surgery



(C) After total posterior palate repositioning



(D) Panoramic view showing the miniplate and distractor

FIGURES 46-112A THROUGH D Lateral cephalometric radiographic sequence, showing maxillary advancement and posterior palatal repositioning by distraction osteogenesis. *A* Preoperative, *B* immediate after surgery, *C* and after total posterior palate repositioning. *D* Panoramic view, showing the miniplate and distractor in position during the consolidation period.

plates and screws (Figures 46-117 through 46-119).

Distraction Protocol

Immediately after surgery, the patient will develop velopharyngeal incompetence because of the maxillary advancement. The activation starts 7 days after surgery at the rate of 0.5 mm every 12 hours. The velopharyngeal incompetence is checked radiographically and via speech evaluation, and distraction continues until the incompetence is corrected. Sixty days of consolidation period are needed before distractor removal.

Biomechanical and Surgical Considerations

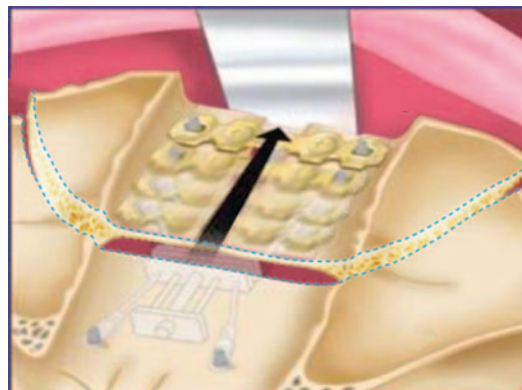
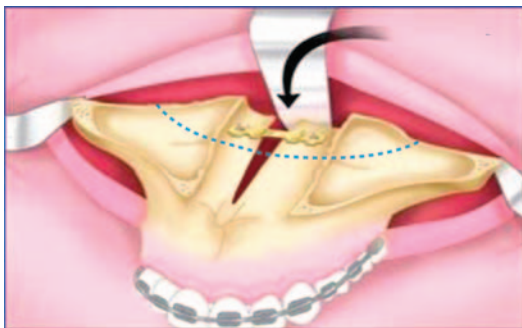
1. Because of the anatomy of the palate, the distractor used is a 12 mm rod, which only allows for a 12 mm distraction. If at the end

of the 12 mm more distraction is needed, then under sedation, the same distractor can be used by removing the screws from the two anterior arms, reversing the rod, and initiating new fixation of the anterior arms to start distraction again.

2. The average acute maxillomalar advancement of a cleft palate patient with a hypoplastic midface is usually 8 mm. The palate activation will include the amount of maxillomalar advancement plus the millimeters needed to correct the incompetence.
3. Significant bending of the posterior arms is usually seen during distraction, owing to the significant forces necessary to push back the posterior palate in operated cleft patients.
4. Pre-bending of the posterior arms is necessary for adapting to the anatomy of the soft palate.



FIGURES 46-113 THROUGH 46-116 Facial and dental changes after maxillary movements.



FIGURES 46-117 THROUGH 46-119 Diagram of the patient in Figures 46-113 through 46-116 with a complete unilateral cleft lip and palate, demonstrating simultaneous Le Fort I maxillary advancement, and palatal posterior repositioning by distraction osteogenesis. Note the fixation of the distraction device and the nasal plate after Le Fort I down fracture, the nasal view with the transverse and lateral palatal osteotomies, maxillary rigid fixation, and the palatal distractor in place.

Velopharyngeal Incompetence

Description of the Problem

The use of pharyngoplasties, pharyngeal flaps, and secondary push-backs to correct velopharyngeal incompetence has been overcome by distraction osteogenesis of the palatine bones to project the palate posteriorly. This technique permits titration of the movement until the velopharyngeal competence is achieved, with predictable results and a low morbidity, avoiding hyponasality, snoring, and nasal obstruction.

Surgical Technique

The Digman retractor is used to expose the palate. An incision is made through the mucosa from first molar to first molar in a horseshoe fashion.

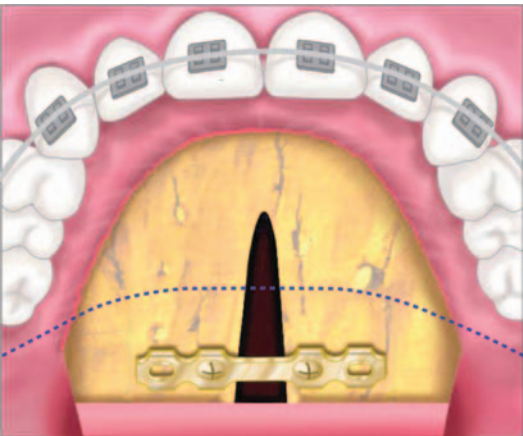
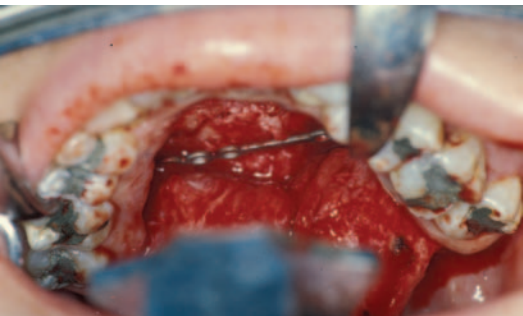
The flap is reflected, preserving the palatine arteries, and a miniplate and a dental implant handpiece are used to fix the palatine bones together. Then, a horizontal osteotomy is performed to design the distraction disk (Figures 46-120 through 46-123).

The flap is repositioned and a 12 mm distractor is fixed transmucosally. Its two

posterior arms engage the miniplate that is already in place, and the two anterior arms are fixed to the anterior maxilla. The flap is sutured and the distractor is activated 2 mm (Figures 46-122 through 46-124).

Distraction Protocol

Activation starts 7 days after surgery at the rate of 0.5 mm every 12 hours. The velopharyngeal incompetence is checked by radiographic and speech evaluation, and distraction continues until the incompetence is corrected. A 60-day



FIGURES 46-120 AND 46-121 Posterior palate distraction technique, when a Le Fort I is not necessary as part of the treatment. Reflection of the palatal mucosa to fix with a miniplate to unite the palatine bones with a miniplate. Diagram representation of the horizontal osteotomy to perform the distraction disk.

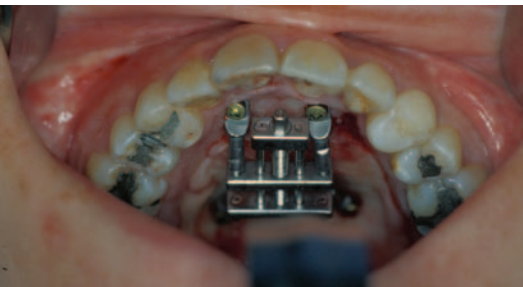
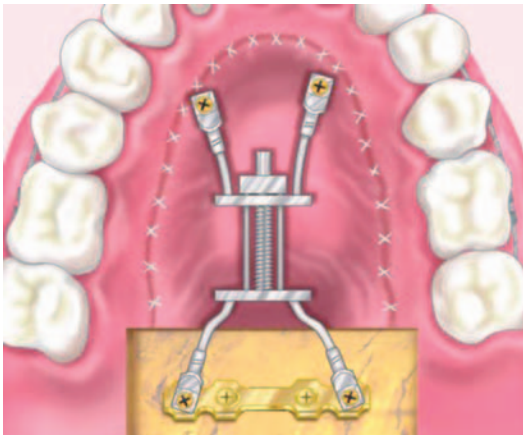


FIGURE 46-122 Transmucosal fixation of the 12 mm distraction appliance after the flap is repositioned and sutured.



FIGURES 46-123 AND 46-124 The two anterior arms are screwed to the premaxilla and its two posterior arms engaged to the previously fixed miniplate.

consolidation period is needed before distractor removal (Figures 46-125 through 46-127).

Discussion

A major drawback of transport osteogenesis is the total treatment duration and the need for a long follow-up. There is no doubt about the advantages and benefits of the present technique, but refining several details could benefit the patient in terms of overall treatment time, by considering the use of bone morphogenetic proteins to accelerate the mineralization process, and reduction of the consolidation period and reconstruction plate phase to maintain the segments in rigid fixation for less than a year. New miniaturized, multidirectional devices to improve the surgical technique and patient's comfort are needed.

A second ambulatory surgery is indicated to remove the distractors and to perform docking-site surgery. The experience in orthopedics and maxillofacial surgery has demonstrated that docking-site surgery should be considered to complete the overall treatment for stable results. Improper management of this surgical stage will result in malunion, fibrous union, or displacement of the bone segments. Poor results are more likely if the docking site is wide, if heavy



FIGURES 46-125 AND 46-126 Radiographic lateral cephalic evaluation during distraction and after completion of distraction showing narrowing the airway.

muscles are involved, or if the site went through bone resorption, generated as a consequence of oral fluids filtration. The progressive soft tissue shrinkage observed after 18 months of consolidation could be explained by the adaptive changes of distraction after the first stages, where there is proliferation of numerous cell types, growth factors and neoangiogenesis, peripheral appliance fibrosis, and foreign body reaction produced within the soft and hard tissues. We have applied minimally invasive distraction surgical techniques: avoiding overheating; limiting surgical exposure; transmucosal appliance fixation; and careful two-layers closure underneath the distractors to preserve the biologic environment. After surgery, good oral hygiene, a liquid diet for the



FIGURE 46-127 Cephalometric tracing. Posterior palatal repositioning during the first (blue) and second (red) distraction movements with the same distractor in two trips.

first 3 weeks, and slow progressive muscles rehabilitation could have influences in the amount of initial edema and promotion of faster surgical recovery.

Conclusions

Distraction osteogenesis has yielded both stability and excellent clinical results with the use of intraoral distraction techniques for reconstructing small and large defects. The advantages of this technique over the traditional reconstruction are overwhelming: there is no need for bone grafts or extraoral facial scars; it can be performed as an ambulatory surgery without hospitalization; and it reduces treatment costs. By providing the same new soft and hard tissues as the original ones, the area is capable of receiving dental fixtures and prostheses to recover both esthetics and function. The multiple bone transport system permits mandibular and maxillary reconstruction for very difficult clinical situations, with low morbidity, although requiring patient cooperation, dedication, and close follow-up. The surgical technique is sensitive in terms of distraction protocol and time for a good mineralization. The fixation armamentarium needs more bioengineering studies to produce adequate distractors. Long

treatment time is devoted when multiple distracted segments are involved.

Bone and soft tissue remodeling is a multifactor process, mediated by biomechanics, bone biology, and molecular biology. Distraction osteohistogenesis consists of 5 very important stages that cannot be violated:

1. Surgical through-and-through osteotomies, to obtain a complete separation of the segments
2. A latency period, to allow the collagen fibers to form and organize
3. A distraction period, to produce the soft and hard tissues stretching
4. Consolidation, for proper mineralization
5. Remodeling, which is the last stage, but the most important one for obtaining the cosmetic results

We observed, in the results of all the distraction techniques, progressive soft tissue shrinkage up to 18 months after surgery. There is a need for more data and more molecular biology research to elucidate the cell-cell communication, for predicting the final surgical outcome and to be able to plan the treatment accordingly.

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Multidirectional Bone Transport Using an Internal Distraction Device

Hideharu Hibi, Yoichi Yamada and Minoru Ueda

Reconstructing large segmental defects of the mandible is challenging. Distraction osteogenesis (DO) has been used as an alternative to microsurgical bone grafts derived from the iliac crest, scapula, or fibula. Costantino and colleagues, Sawaki and colleagues, and Klein reported successful clinical outcomes for DO-based mandibular reconstruction using distraction devices that facilitated multidirectional bone transport,¹⁻³ but these devices require external application, which can cause problems, such as social inconvenience and facial scarring. Guerrero and colleagues and Herford proposed solutions to the aforementioned problems that were based on the use of internal distraction devices,^{4,5} and although their techniques are valuable, they appear to be limited in terms of the size and position of the defect that can be treated. We developed a novel multidirectional internal distraction device that can be used to reconstruct a variety of segmental defects of the mandible.⁶

Internal Multidirectional Distraction Device

Our internal multidirectional distraction device facilitates bifocal or trifocal bone transport.⁷ The device comprises a bridging reconstruction plate, brackets with miniplates, traction mechanisms, and wires (Figure 47-1). The activated traction mechanisms pull and slide the brackets on the rail of the reconstruction plate via wires, thereby moving the transport disks, which are fixed to the miniplates along the rail. Resetting the traction mechanism and wires allows for transportation over any distance. An optional V-shaped connector that joins the traction mechanism to the reconstruction plate allows the device to be used on the ascending ramus or a condylar implant (Figure 47-2).

Indications

Indications for internal device-based DO are segmental bone defects of the mandible with a



FIGURE 47-1 Internal multidirectional distraction device. The bridging reconstruction plate (yellow), brackets (green) with miniplates, and traction mechanisms (blue and red) are illustrated. The activated traction mechanisms pull and slide the brackets along the rail of the reconstruction plate via wires and thereby carry the transport disks (which are fixed to the miniplates) along the rail.



FIGURE 47-2 Unilateral bone transport using the distraction device with an optional V-shaped connector for the traction mechanism and the reconstruction plate. This connector allows the device to be used on the ascending ramus or a condylar implant (inset).

residual bone fragment that is sufficiently large to provide a transport disk. Special considerations are required for compromised mandibles. Specifically, irradiated mandibles may require hyperbaric oxygen therapy² to recover the healing capacity of the damaged tissue and to prevent osteoradionecrosis. In addition, if there is an insufficient amount of soft tissue to cover the reconstruction plate, additional wrapping with muscle or skin flaps may be required to minimize the risk of exposure.

Advantages and Disadvantages

An internal distraction device without transcutaneous pins eliminates the problems that arise owing to the use of pins, including scarring, infection, social inconvenience, and resistance of the skin or muscles to distraction. The combination of osteosyntheses and brackets allows for rigid fixation and accurate control of the transport disk. Such a rigid support system based on the use of a common rail ensures that the transport disks are docked firmly owing to the creation of a deliberately compressive force and little discrepancy without active vector control, although the disks can move in multiple directions along the rail. Staged application of the device is also possible to treat compromised patients or patients with a poor prognosis. The traction mechanism allows the retraction force that is exerted on the transport disk during distraction to be measured using a spring scale or a torque gauge. Although a portion of the traction mechanism is external, the external portion of the mechanism is usually obscured by the ear and/or hair. Resetting the mechanism can reduce the amount of external projection.

Surgical Technique

A three-dimensional model of the mandible facilitates preoperative planning, preadjustment of the distraction device, and simulation of surgery and bone transport. Application of the reconstruction plate and the availability of the transport disk depend on the size and shape of

the residual bone fragment. The submandibular or intraoral approach leads to appropriate osteotomies and fixation of the distraction device. Care should be taken during surgery to maintain an adequate blood supply to the transport disk and to minimize periosteal stripping. The bulk of the distraction device is implanted except for a portion of the traction mechanism that is passed through the skin via a stub incision within the retromandibular area to act as a drain also.

Distraction is performed at an appropriate rate after a latency period. Following the completion of bone transport, the traction mechanism may be detached; if necessary, the ends of the residual fragment or the transport disk at the docking site can be prepared for the application of autologous bone or osteogenic material.⁸ The rest of the distraction device remains in place throughout the consolidation period.

Properties of Regenerated Tissue

The properties of the tissue that is regenerated during bone transport depend on the properties of the transport disk; they include height, width, whether mucosa is attached, and which neurovascular bundle is involved. Damage to the mental nerve or the tooth should be avoided, and elongation of the attached mucosa is preferred. In the lateral region, the posterior transport disk may not have mucosa attached, which allows for faster consolidation owing to a better supply of blood, whereas the anterior transport disk elongates the attached mucosa posteriorly with or without the involvement of the tooth (Figure 47-3). DO in the medial and lateral regions involves the symphysis. The regenerated tissue may straighten even if the transport disk moves in multiple directions, which results in an anterior body that is narrow or absent. By contrast, bilateral transport disks finally dock and compose the anterior body, the form of which depends on the size of the transport disks. An additional lingual plate can be inserted to support the regenerated tissue, although this can compromise the supply of blood to the transport disk. Staged or intermittent DO

can allow the multiangled anterior body to assume the shape of the symphysis. The application of physical stimuli, chemical factors, or osteogenic cells⁹ to accelerate consolidation should facilitate further development of this promising method of DO (Figure 47-4).

Case Report

A 59-year-old male had undergone segmental resection of the mandible owing to an ameloblastoma and immediate reconstruction with an iliac

bone graft 6 years previously. The grafted bone was lost owing to an infection, which resulted in a segmental bone defect bridged by two plates and deformity of the lower third of the face (Figure 47-5).

A stereolithographic mandibular model was constructed based on a computed tomographic scan. The defect was 8 cm long, and the reconstruction plate was shaped to support the lower contour of the face. Osteotomy lines were designed for the left ramus and the right body between the mental foramen and first premolar. Four

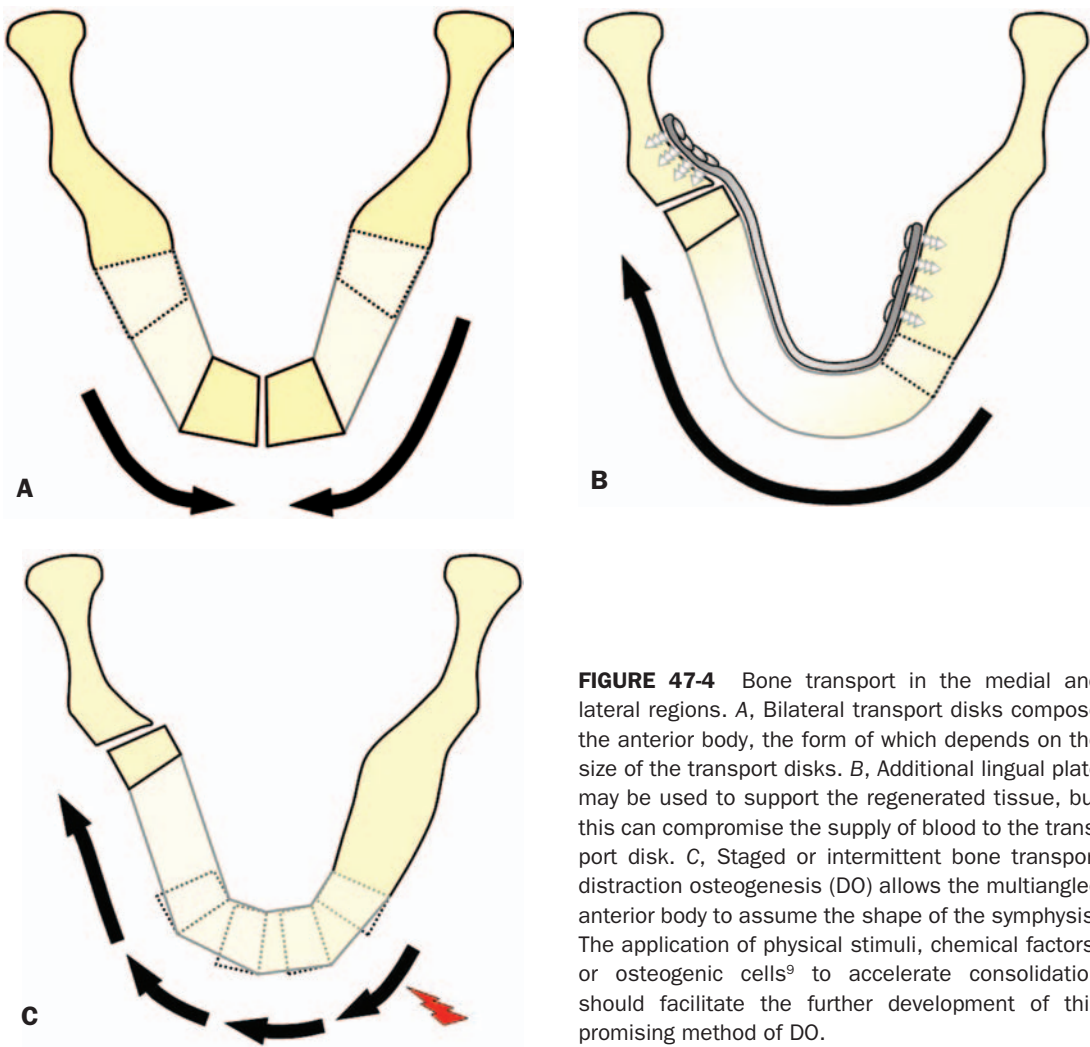


FIGURE 47-4 Bone transport in the medial and lateral regions. *A*, Bilateral transport disks compose the anterior body, the form of which depends on the size of the transport disks. *B*, Additional lingual plate may be used to support the regenerated tissue, but this can compromise the supply of blood to the transport disk. *C*, Staged or intermittent bone transport distraction osteogenesis (DO) allows the multiangled anterior body to assume the shape of the symphysis. The application of physical stimuli, chemical factors, or osteogenic cells⁹ to accelerate consolidation should facilitate the further development of this promising method of DO.

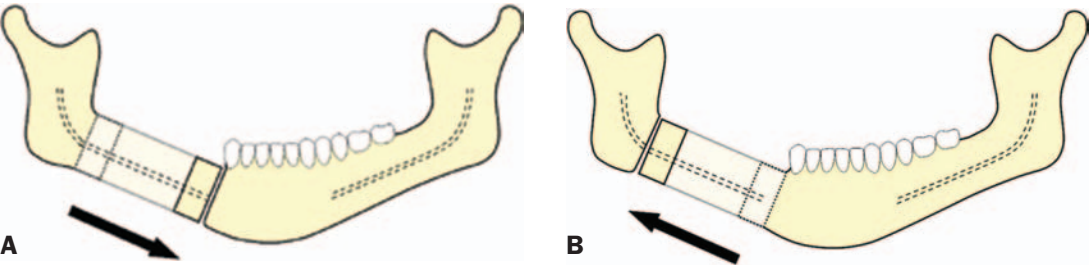


FIGURE 47-3 Bone transport in the lateral region. *A*, Posterior transport disk. This disk may not have mucosa attached but allows for faster consolidation owing to a better blood supply. *B*, Anterior transport disk. This disk elongates the attached mucosa posteriorly in the direction of bone transport with or without the tooth.

miniplates were selected and adapted to the anterolateral and inferior surfaces of the bilateral transport disks. Following osteotomy simulations, the components of the distraction device were assembled and fixed to the model using screws. Bone transport was confirmed by activation of the traction mechanism (Figure 47-6).

Surgery was performed as simulated using a submandibular approach via an incision that was located along a residual scar (Figure 47-7). Distraction was initiated at a rate of 0.5 mm twice per day after 7 days of latency. Distraction was carried out for 44 days (Figure 47-8). The



FIGURE 47-5 A 59-year-old male patient with a mandibular segmental defect. A, Deformity of the lower third of the face. B, Absence of a residual ridge associated with the bone defect. C, Segmental defect bridged by two plates.

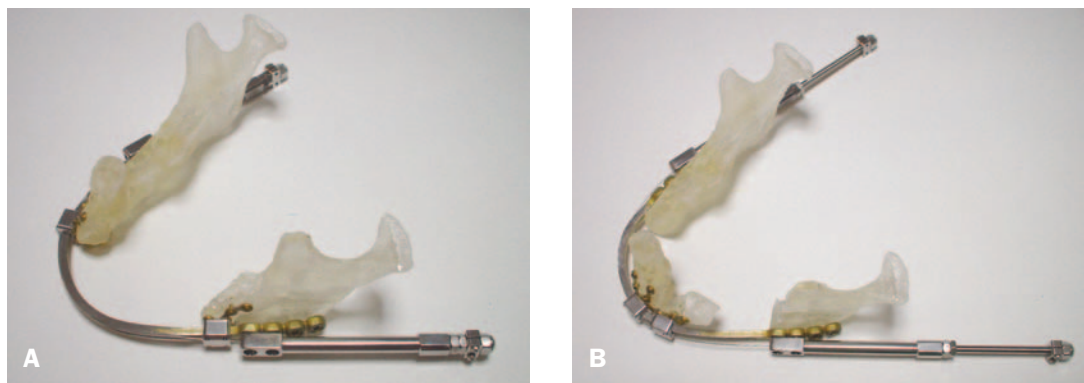


FIGURE 47-6 Distraction device and simulation. A, Distraction device assembled on a three-dimensional stereolithographic model of the mandible. B, Simulation of bone transport with activated traction mechanisms.



FIGURE 47-8 Activation of the traction mechanism.

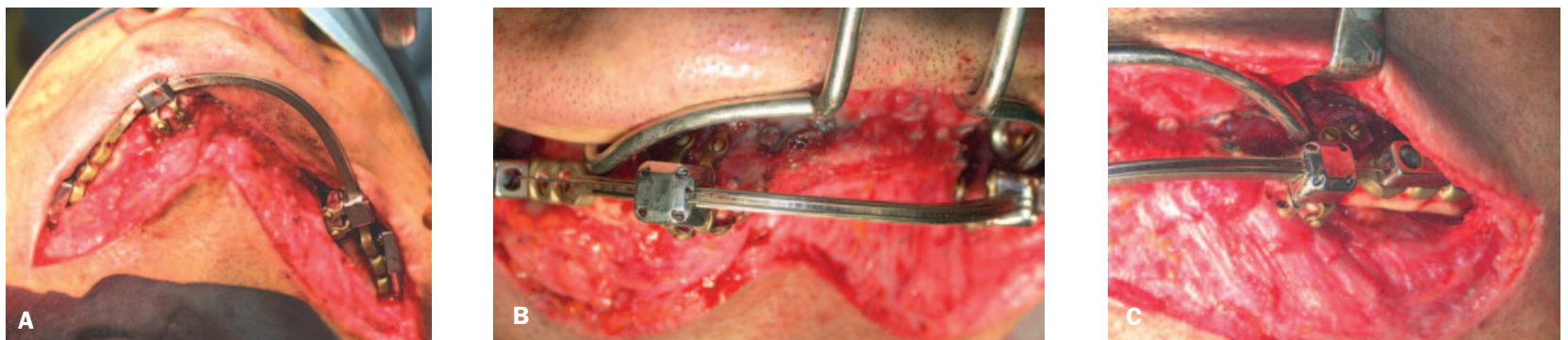


FIGURE 47-7 Osteotomies and fixation of the distraction device. A, Surgery performed as simulated. B, Rail of the reconstruction plate shaped in three dimensions. C, Bracket sliding along the rail with the transport disk.

two transport disks met without complications. The traction mechanisms were removed, and tissue-engineered osteogenic material⁸ that comprised autologous culture-expanded mesenchymal stem cells and platelet-rich plasma was applied to the docking site. The patient was able to carry out the normal activities of daily living during the consolidation period (Figure 47-9).

A series of postoperative panoramic radiographs revealed that the transport disks had moved as simulated and that the radiopacity of the distraction zones had increased (Figure 47-10). The residual ridge on the right side had elongated together with the attached mucosa and had assumed the shape of an arch (Figure 47-11).

Conclusion

Bone transport using an internal multidirectional distraction device can be used to reconstruct the mandible without inconvenience. The combination of this method of bone transport and technologies such as tissue engineering should allow further refinement of this promising method of DO.

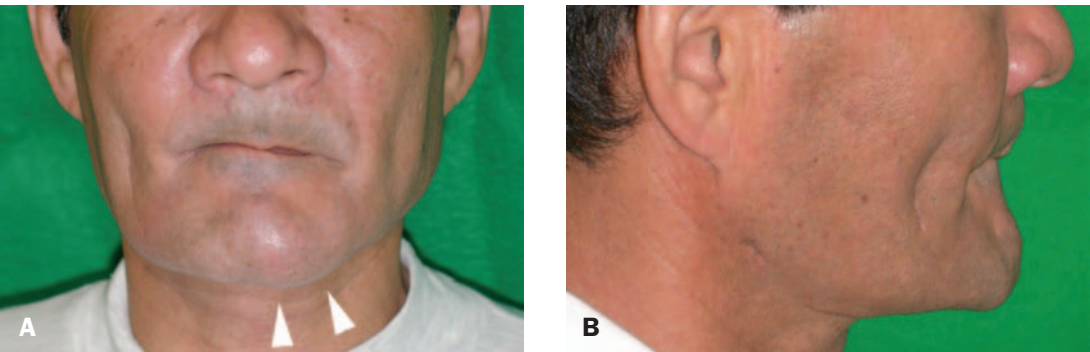


FIGURE 47-9 Internal distraction device without the traction mechanism during the consolidation period. A, Internal brackets (arrows). B, Retromandibular area after detachment of the traction mechanism.



FIGURE 47-11 Intraoral view immediately after distraction. Note the arch-shaped ridge with the elongated mucosa attached (between the arrows).



FIGURE 47-10 Panoramic radiographs showing bone transport and consolidation. A, Immediately after surgery. B, Immediately after distraction. C, Three months after distraction. Note the increased radiopacity of the distracted zones.

Acknowledgment

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Use of Tissue-Engineered Osteogenic Material for Alveolar Cleft Osteoplasty

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The reconstruction of alveolar cleft defects has been the subject of intense investigations, and the most widely accepted approach is secondary alveolar cleft osteoplasty using autologous bone grafting in the mixed dentition phase.^{1,2} Most bone grafts have been particulate cancellous bone and marrow harvested from the anterior iliac crest, and this represents the standard material with which other materials from the rib, mandible, calvarium, and tibia are compared.¹⁻³ Donor-site morbidity is a critical factor in deciding which site to use for harvesting bone, and the use of allogeneic or xenogeneic materials may eliminate this concern but not the risk of disease transmission. Osteoinductive agents such as human bone morphogenetic proteins⁴⁻⁶ can solve these problems and are expected to be used clinically in the future. An alternative replacement for autologous bone grafts in bone augmentation procedures is the use of tissue-engineered osteogenic material (TEOM) comprising autologous mesenchymal stem cells (MSCs) and platelet-rich plasma (PRP), and this method offers predictable results with minimal donor-site morbidity.^{7,8} This chapter describes the TEOM and its clinical application in alveolar cleft osteoplasty.

Materials and Method

Preparation of TEOM

The TEOM was prepared from autologous materials (Figure 48-1). Autologous blood (200–400 mL) was harvested to extract serum (100–200 mL) several times, and 300 to 600 mL of serum was cryopreserved. Approximately 10 mL of the bone marrow aspirate was collected from the anterior iliac crest with a 14-gauge biopsy needle under local anesthesia without any additional discomfort to the patient. The MSCs were isolated from the marrow aspirates and cultured as reported.^{7,9} The cells were suspended in low-glucose Dulbecco's modified Eagle's medium containing L-glutamine, penicillin, and streptomycin (Cambrex, Walkersville, MD), supplemented with the 15% autologous serum, and incubated at 37°C in a humidified atmosphere

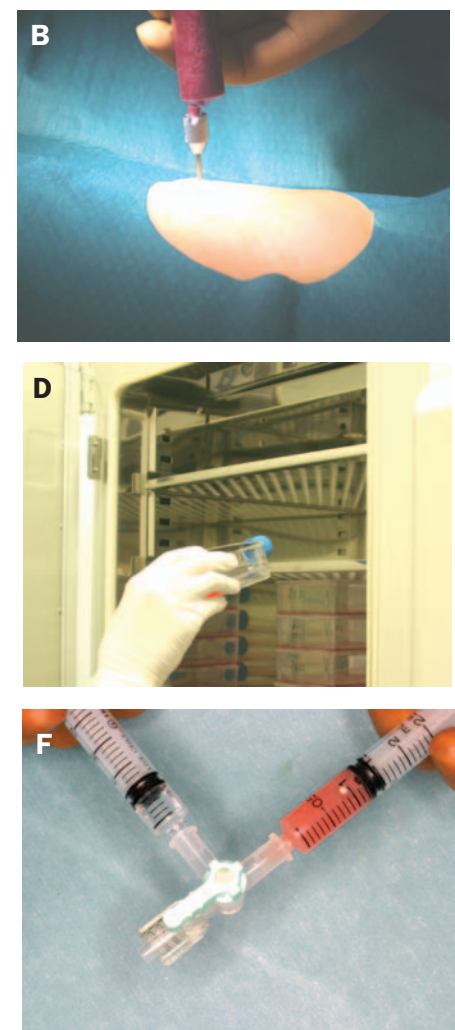
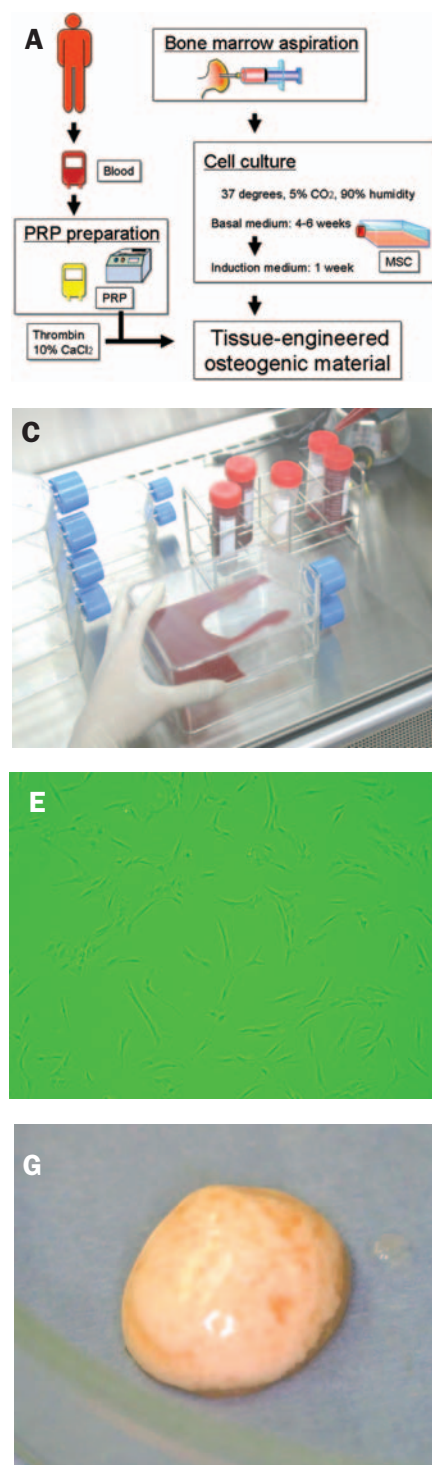


FIGURE 48-1 Preparation of tissue-engineered osteogenic material. A, Preparation of mesenchymal stem cells (MSCs), platelet-rich plasma (PRP), and tissue-engineered osteogenic material. B, Aspiration of bone marrow from the anterior iliac crest under local anesthesia. C, Preparation of bone marrow aspirates for cultivating MSCs in a cell processing unit. D, Incubation at 37°C, 5% CO₂, and 90% humidity. E, Phase-contrast microscopic image of MSCs in culture. F, Mixing materials of tissue-engineered osteogenic material. The left syringe contains air, calcium chloride, and human thrombin; the right syringe contains PRP and MSCs. G, Tissue-engineered osteogenic material in gel form.

containing 5% CO₂ and 95% air. The MSCs were replated and expanded for 4 to 6 weeks and then induced to be osteogenic in character for another week with 100 nM dexamethasone, 10 mM β -glycerophosphate, and 50 μ g/mL ascorbic acid-2-phosphate (Sigma-Aldrich, St. Louis, MO). The differentiated MSCs were confirmed by detecting alkaline phosphatase activity. One day before surgery, approximately 10 mL of PRP was extracted from 100 mL of autologous blood using centrifugation and a selective collection technique.^{7,10} During the surgery, the differentiated MSCs were mixed with 6 mL of the PRP, 1 mL of 10% calcium chloride solution containing 1,000 U of human thrombin, and 1 mL of air, with the total amount of each of these materials varying according to need. The mixture polymerized into a gel form of the TEOM within 5 seconds.

Roles of Ingredients

The three prerequisites for tissue engineering are cells, cytokines, and a matrix.^{9,11–13} The TEOM used in this study contained autologous MSCs and PRP. The PRP contains not only fibrinogen that forms a fibrin network acting as a matrix but also chemical substances, such as platelet-derived growth factor, transforming growth factor β , vascular endothelial growth factor, and insulin-like growth factor. These factors contribute to cellular proliferation, matrix formation, collagen synthesis, osteoid production, and other processes that accelerate tissue regeneration.¹⁰

Indication

TEOM can be used as a graft material for spaces created directly adjacent to bony surfaces such as inlay-type graft for a maxillary sinus lifting procedure with a simultaneous implant^{7,8} and an onlay-type graft using the membrane technique for guided bone regeneration. A recent report from a clinical trial indicates that such grafts and injection into immature tissue in distracted zones accelerate the healing process.¹⁴ Recipients need to satisfy the requirements regarding body weight and hemoglobin in the guidelines for autologous blood transfusion.

Case Report

A 3-month-old female patient born with a congenital left unilateral cleft lip and alveolus had undergone cheiloplasty that resulted in no remaining oronasal fistula. At 9 years of age, computed tomograms (CTs) revealed that the left maxillary canine, lateral, and supernumerary incisors had formed approximately half of their roots and that they closely surrounded the alveolar cleft bony defect, which was 10 mm wide and 13 mm deep anteroposteriorly (Figure 48-2). The left central incisor had been orthodontically overcorrected owing to previous severe rotation

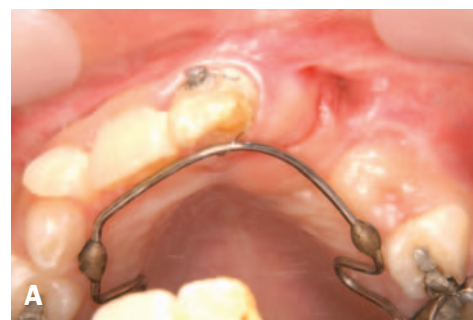


FIGURE 48-2 Unilateral alveolar cleft of the 9-year-old female patient. A, Intraoral view. B, Three-dimensional computed tomogram demonstrating the unerupted left maxillary canine, lateral incisor, and alveolar bony defect.

and distal location. When secondary alveolar cleft osteoplasty was indicated, the patient and her parents were informed about the nature of the TEOM and granted their consent. The clinical protocol as translational research of TEOM was approved by the Ethics Committee of Nagoya University.

Operative Technique

Following a 3 cm–long mucosal incision at the level of the labiogingival junction, dissections were made in the ingrown scar tissue to reach the bony surface of the cleft walls (Figure 48-3). The tissue was then elevated in the subperiosteal plane to the levels of the anterior nasal spine

and the lateral piriform rim superiorly and the alveolar ridges inferiorly while taking care not to damage the unerupted teeth and the content of the incisive canal. The flaps of the nasal floor and the oral mucosa formed the ceiling and the floor of the cleft cavity, respectively. The ceiling, floor, and front walls of the defect were supported with a 0.1 mm–thick titanium mesh plate (Stryker, Kalamazoo, MI). The pouch thus created was filled with 2.4 mL of the prepared TEOM, including 5.0×10^7 differentiated MSCs and 1.8 mL of the PRP (8.9×10^5 platelets/ μ L: 313% higher than the original whole blood), through a syringe using a packer. Following release incisions in the periosteum and the scar tissue of the flaps

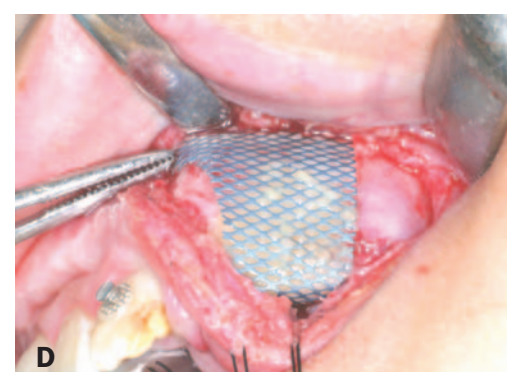


FIGURE 48-3 Intraoperative views. A, Exposed alveolar cleft defect. B, Titanium mesh plate for supporting the mucoperiosteal flap. C, Cleft cavity grafted with the tissue-engineered osteogenic material. D, Graft covered with the titanium mesh plate.

to allow them to cover the grafted area, the wound was consequently closed without tension.

Postoperative Course and Properties of the Regenerated Bone

The patient exhibited an uneventful postoperative course. The radiopacity of serial CTs slicing the middle level of the alveolar cleft in the grafted region increased gradually over time (Figure 48-4). Dome-shaped radiopaque images with 233 Hounsfield units (HU) faced together and extended from the cleft bony walls inside the cavity after 3 months and were fused together into an image with 324 HU after 6 months. The image increased in radiopacity to 447 HU, covering 79% of the cavity in 9 months, and at the bony bridge, the lateral and supernumerary incisors horizontally approximated from their original positions in the respective major and minor segments. The incisive canal was reconstructed just medial to the bridge. The erupting canine and lateral incisor pushed the mesh plate vertically, and the mucosa covering the cleft consequently swelled and thinned. A mucosal cut was made in the crest of the alveolar ridge over these teeth, and the part of the plate overlying the teeth was removed under local anesthesia. The canine, lateral, and supernumerary incisors then erupted at approximately the same time (Figure 48-5).



FIGURE 48-5 Canine, lateral, and supernumerary incisors erupting in the reconstructed alveolar ridge.

Advantages and Disadvantages

Advantages

TEOM technology has none of the restrictions of immunogenicity or risk of disease transmission that may be derived from allogeneic and xenogeneic materials. The gel form of the TEOM enables it to reach any surface, such as the bottom of microthreads of dental implants, where other forms, including solid, may not reach. The TEOM regenerates the bone in the alveolar cleft defect without the donor-site morbidity that is

associated with the use of an autologous bone graft. Whereas grafted bone remodels itself owing to apposition following resorption, the TEOM can form new bone owing to apposition primarily rather than resorption. The TEOM and its regenerated bone also offer erupting routes to impacted teeth forming their own roots without possible obstruction of such routes associated with using graft materials that are less resorbable. The possibility of harvesting, isolating, and cryopreserving a certain number of MSCs enables TEOM and tissue-engineered chondrogenic, adipogenic, myogenic, or fibrogenic material to be supplied⁹ repeatedly and without limits in volume as needed. Younger patients have more MSCs, and this repeatability may, in the future, facilitate sequential treatments of cleft patients.

Disadvantages

The preparation of the TEOM requires several collections of 200 to 300 mL of autologous blood, approximately 5 to 7 weeks for cell processing, and the facilities used must be based on such regulations as the Good Manufacturing Practice of the US Food and Drug Administration.¹⁵ Since TEOM remains in gel form, the mucoperiosteal flaps require support in the proper reconstruction of alveolar morphology. This could be overcome by the use of the TIME technique,¹⁶ which involves using a titanium mesh plate that facilitates a rigid space without disturbing the blood supply from the overlying flaps. However, this plate must be removed before tooth eruption. The use of resorbable membranes may solve this problem, but they inhibit the blood supply. The skeletal frame or carriers of biodegradable material such as polylactic acid polymer or collagen may also serve as other alternatives in preventing inhibition of blood flow.^{17, 18}

Conclusion

TEOM may be considered a clinically useful graft biomaterial for alveolar cleft osteoplasty. Tissue engineering technology enables the processing of autologous MSCs to graft materials not only for bone but also for cartilage, fat, muscle, or dermis. This technology may, in the future, facilitate sequential and holistic treatment of cleft patients.

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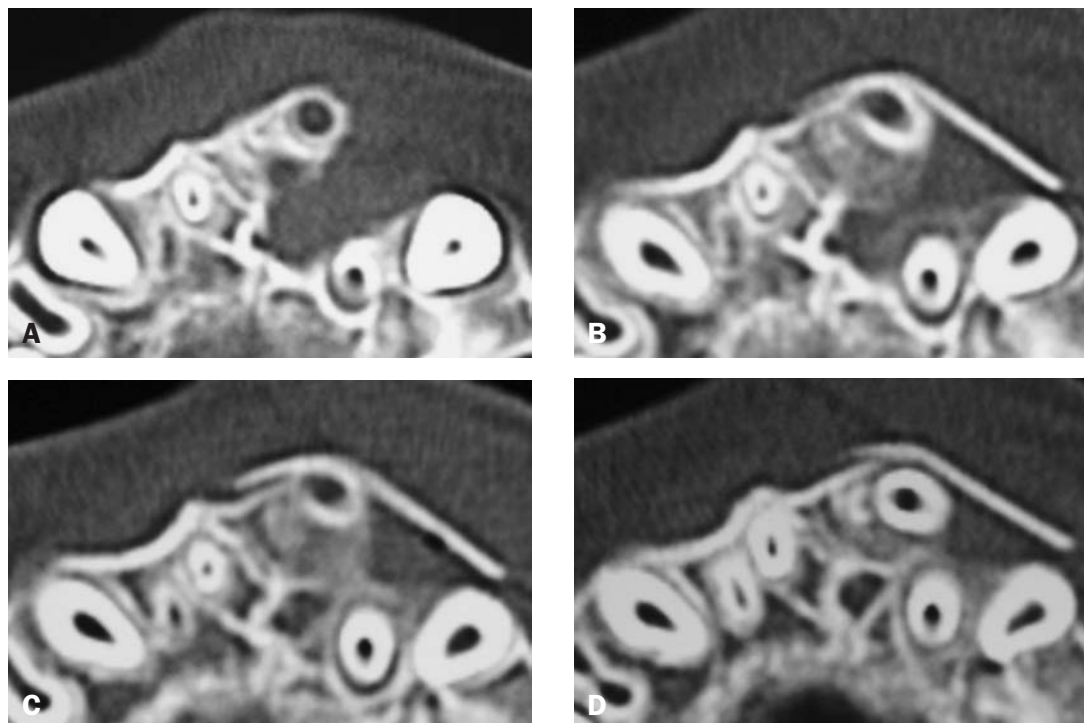


FIGURE 48-4 Serial computed tomograms slicing the middle level of the alveolar cleft. A, Preoperation. B, Three months postoperation. Dome-shaped radiopaque images facing together and extending from the cleft bony walls inside the cavity. C, Six months postoperation. Fused image in the cleft cavity. D, Nine months postoperation. Lateral and supernumerary incisors approximated in the bony bridge lateral to the reconstructed incisive canal.

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Maxillary Distraction for Patients with Cleft Lip and Palate

Lim K. Cheung and Hannah Daile P. Chua

Maxillary hypoplasia is a common developmental problem in cleft lip and palate (CLP) deformities and normally results from a combination of a reduction in midfacial growth and the effects of surgical scarring owing to cleft palate repair. Patients with CLP therefore classically present with Class III malocclusion, a retruded midface, and a narrow palatal arch. Since the 1970s, CLP deformities have conventionally been corrected by orthognathic surgery,¹⁻⁶ and since the late 1990s, distraction osteogenesis has been recognized as an acceptable alternative for treatment of maxillary hypoplasia in patients with CLP.⁷ The aim of both techniques is to advance and downgraft the maxilla to a normal position in relation to the skull and the occlusion.

The clinical application of distraction in managing CLP was first reported in 1995 by Cohen and colleagues, who designed a miniature distraction system for the midface that permitted maxillary and midfacial advancement in young children.⁷ The authors reported that this device produced no clinical complications and claimed that using distraction to correct severe midfacial hypoplasia in children enables early intervention with a potentially less invasive technique than conventional orthognathic surgery requiring bone grafting. In the same year, Polley and Figueroa successfully treated 18 patients with CLP by using a rigid external distractor.⁸ In Europe, Swennen and colleagues performed distraction for CLP with the use of a Delaire face mask.⁹

A considerable body of literature now exists on the treatment of CLP by both conventional osteotomy and distraction osteogenesis. Many surgeons may find it difficult to decide which technique offers better results or may be uncertain about the factors influencing that choice. We conducted a meta-analysis of the scientific literature to assist surgeons in making an informed decision between distraction and orthognathic surgery for CLP deformities.¹⁰ The variables that can influence this choice are as follows: the age of the patient, the osteotomy design, any concurrent mandibular procedure, the amount

of advancement, the need for bone grafting, postoperative care, complications, stability and relapse, and the impact on speech and facial esthetics.

Factors Affecting Choice of Therapy

Age of Patients

Conventional cleft osteotomies are normally recommended to patients only when mandibular growth has ceased. Most patients who receive such treatment are aged 16 years or older. Few younger patients have maxillary osteotomies because of the fear that they might terminate maxillary growth prematurely or that continuing mandibular growth might induce a relapse into Class III malocclusion. Conventional cleft osteotomies are performed on children and teenagers only in exceptional circumstances, such as if they face marked psychological pressure from peers or at school. The few surgeons who have performed distraction on teenagers younger than 16 years have aimed to minimize facial deformities. Significant overdistracted of the maxilla into Class II has been done to prevent the occlusion developing into Class III and to allow continued mandibular growth. However, the exact amount of overcorrection for children of different ages cannot be predicted with any reliability, and there is also no evidence that the maxilla will grow further after distraction. If distraction is performed before full maturation, the patients may have to undergo a further osteotomy or distraction later in life. This information should be made known to young patients and their parents before they consent to the procedure.

Osteotomy Design

Surgical planning for distraction and conventional osteotomy for CLP is similar and should be based on the diagnosis of the extent and severity of the maxillary deformity. To obtain satisfactory results, it is important for both techniques to be integrated with presurgical and postsurgical orthodontics. Just as for conventional osteotomy, dental-model surgery is required before distraction

to estimate the degree of distraction required and to plan the distraction vector for a functional occlusal outcome. Surgeons also need to be able to make a presurgical prediction, as in conventional orthognathic surgery, so that patients with CLP can appreciate the likely esthetic result of surgery before they give permission for an operation to be performed.

Similar Le Fort maxillary osteotomy cuts at levels I, II, and III can be made in both distraction and osteotomy. The differences between the two techniques lie in the need to complete the posterior maxillary cut at the pterygomaxillary junction, downfracturing, mobilization of the maxillary segments, and the feasibility of segmentalization. It has been demonstrated that an incompletely cut Le Fort I osteotomy can be distracted by externally placed distractors.^{11,12} A drawback is that these distractors can create considerable tension, which tends to make the distraction process painful. There is also a danger that bone-borne distractors may be loosened or that the anterior teeth may be loosened or tilted with the use of tooth-borne distractors. We recommend that all maxillary osteotomy cuts be completed and the segment be downfractured. The maxilla should be gently mobilized to free it from any bone attachment and then positioned using a vector guidance device to enable the distractor to transport the maxillary segment to its planned functional occlusion.

Maxillary distraction is more effective when it is in a single segment and the cleft alveolus is grafted beforehand. Otherwise, the distractors may push the nongrafted alveolus segments together by closing the alveolar cleft space, thereby losing the benefit of advancing the maxilla forward. None of the reported cases of distraction have involved segmentalization of the Le Fort I segment. We have performed distraction on cleft maxillae that are divided into two or three segments, but these segments must be bridged together by miniplates and screws.

Concurrent Mandibular Procedures

If any deformities are present in the mandible, a concurrent mandibular osteotomy can be

performed to achieve the best esthetic balance. The mandibles are commonly set back during orthognathic surgery to reduce the extent of maxillary advancement because the surgeons are concerned about the technical difficulty of immediate transposition of the scarred cleft maxilla and about the risk of vascular ischemia and relapse. Owing to the gradual movement of distraction, this technique is able to overcome the physical limitation of scar tension. Hence, surgeons can plan massive surgical movement of the cleft maxilla without needing to consider compensation by mandibular setback.

Surgical Movement

Distraction, either with a pair of internal distractors or with a single external distractor, can achieve maxillary advancement and downgrafting simultaneously. If the maxilla is to be expanded, this outcome can be achieved only after a separate palatal distractor is implanted in the palate. However, a distractor cannot conduct maxillary retrusion, impaction, or contraction movement—all of which can be done with conventional osteotomy techniques. In CLP deformities, the maxilla is normally hypoplastic in all three planes and is therefore correctable by distraction osteogenesis.

Instead of reserving the distraction technique for severe deformities only, surgeons can use it to treat the common cases of cleft maxillary deformity that need small to moderate surgical advancement. Distraction is capable of moving the maxilla more than 20 mm further than the distance that has so far been possible with conventional osteotomy, although only one such case has been reported.¹³ From our experience of using internal maxillary distractors on patients with CLP, conventional osteotomy and distraction can both reliably achieve advancement of 10 mm or less.

The downward vertical movement in distraction should be considered in the surgical planning for patients who have a lack of incisal show at rest and increased freeway space. The extent of vertical movement is determined by the downward angulation of the distraction vector and the extent of horizontal movement along this vector during the simulation model surgery. It is important to know the preferred vertical position of the maxilla, reflected by the amount of upper incisal exposure, so that vector angulation can be planned accordingly.

In the transverse dimension, distraction can lead to a large expansion of the maxilla without creating any oronasal fistula. Such an expansion is generally considered inadvisable in conventional osteotomy of CLP deformities because of the high transverse relapse rate owing to palatal scar tension. Nevertheless, a small extent of transverse expansion is technically feasible during the osteotomy procedure.

Need for Bone Grafting

A definite advantage of distraction over conventional osteotomy is that there is no need for bone grafting because distraction regenerates new bone along its path. According to the reports considered in our meta-analysis, bone grafting was required to bridge osteotomy gaps in more than half of the CLP cases treated by conventional osteotomy.¹⁰ Because distraction osteogenesis does not require bone grafting, there is no donor-site morbidity and the operation time can be reduced accordingly.

It is important to ensure that there is bone-to-bone contact before beginning the distraction procedure to ensure that new bone can be created in the gap, the extent of which is determined by the downward vector. In Le Fort I maxillary distraction, it is not important that the maxilla should be at its original position before distraction as long as the buccal bone of the maxillary anterior wall is in contact. In our surgical planning protocol, we normally set the maxilla about 1 to 2 mm forward from its original position to ensure that it remains free from any bone interlocking or interference while the distractors are being fixed.

Postoperative Care

Similar postoperative care is required after both cleft and noncleft osteotomies. Prophylactic antibiotic treatment is commonly started before the anesthetic is administered and lasts for 1 to 2 days postoperatively. Some centers prescribe steroids to reduce the occurrence of postoperative edema. The use of orthodontic elastic during the first postoperative 6 weeks is fairly common after osteotomies, particularly for CLP osteotomies, because of the likelihood of an early skeletal relapse. Surgical splints are also often retained to minimize the chance of an occlusal relapse.

After distraction, postoperative care is related mainly to the activation and maintenance of the distractors. Maxillary distractors are mostly activated after a 3- to 7-day latency period and at a rate of 1 mm per day in two to four rhythms. A consolidation period of 2 to 3 months is common to ensure that the distraction gap is ossified before the distractors are removed. Face-mask distraction may require an extended retention period of up to 1 year. Elastic is also commonly used during the consolidation period, with the aim of closing any residual open bite and maintaining the distracted occlusion. A second operation is normally required after distraction; this operation is done under local anesthesia if external distractors are used and under general anesthesia if internal distractors are used. By contrast, a second operation is not required after a conventional osteotomy unless there is significant surgical relapse.

Complications

Our meta-analysis showed that intraoperative or postoperative morbidities owing to either distraction or conventional osteotomy is low. Complications seem to have occurred in only 60 (4.2%) of the 1,418 patients treated with conventional osteotomy and in only 15 (5.4%) of the 276 patients who underwent distraction osteogenesis. These low proportions are probably underestimates because most studies were retrospective and the details of complications were retrieved mainly from patients' records. Temporary hearing disturbance was reported as a relatively common complication in conventional osteotomy, and it is equally likely to occur with distraction. Several typical complications of conventional osteotomy will not occur if distraction osteogenesis is used, including avascular necrosis, oronasal communication, intraoperative hemorrhage, and intraoperative avulsion of the osteotomized maxilla. On the other hand, new complications caused by the distractors themselves may develop, such as device failure and skin irritation.

Stability and Relapse

Relatively few studies of cleft maxillary distraction osteogenesis have been published that include postoperative stability and frequency of relapse. From our meta-analysis, follow-up data were recorded from 79 cases, but quantitative data on skeletal relapse were recorded in only 5 of these cases (Table 49-1). By contrast, a considerable body of data on skeletal relapse is available for cases of conventional osteotomy owing to its long history and larger sample. The stability problems related to conventional osteotomies have been better documented than noncleft cases. Despite improvements in internal fixation and modified osteotomy design, the inherent palatal scar and its resistance to any large transposition movement probably contribute to the high rate of relapse in both the horizontal and vertical planes.

In a study conducted by Heliovaara and colleagues, the skeletal stability following Le Fort I osteotomy among 40 consecutive patients with unilateral CLP was evaluated.¹⁴ The mean maxillary advancement was 3.9 mm (range 0–8.9 mm), and the mean vertical lengthening was 4.5 mm (range 0.6–10.5 mm). The mean horizontal and vertical relapses during the first postoperative year were 20.5% and 22.2%, respectively. The authors suggested that there was a significant correlation between the amounts of maxillary advancement and relapse in both the horizontal and vertical planes. In this study, the A point relapsed vertically in the conventional osteotomy group by 6% during the second to eighth postoperative weeks and by 33% during the eighth to twelfth postoperative weeks. The

Table 49-1 Stability following Maxillary Distraction Osteogenesis				
Stability of Distracted Maxilla (Follow-Up Period, yr)		No. of Patients		%
1–2		27		34.18
2–3		52		65.82
Total		79		100
Maxillary Relapse	Amount	No. of Affected Patients	Total Patient Sample	Amount of Advancement (mm)
2 yr postoperatively	5.56%	5	5	9
	Not specified	1	6	1.7
First 6 mo	Not specified	2	2	Not specified

degree of relapse obtained from this study was similar to that recorded by Houston and colleagues, who evaluated the surgical and postsurgical cephalometric changes in maxillary position after transpalatal osteotomy at the Le Fort I level in 30 patients with CLP.¹⁵ The mean horizontal and vertical changes in their study were 9 mm and 3 mm, respectively, and the relapse rates were 7% horizontally and 23% vertically. Posnick and Dagys and Hirano and Suzuki found that after maxillary advancement by conventional orthognathic surgery, relapse of the maxilla ranged from 20 to 30%, despite the insertion of bone grafts and fixation of miniplates.^{16,17} Owing to the relapse problems encountered, Posnick and Taylor advocated overcorrection of the maxilla to overcome the skeletal relapse.¹⁸

Distraction involves gradual advancement of the Le Fort I maxillary segment. Compared with conventional Le Fort I osteotomy, it allows greater protraction distances to be achieved. The technique also allows the soft tissue musculature, which limits the advancement obtained intraoperatively, to accommodate gradually. In contrast to other studies of patients with CLP, our recent study for the first time used a randomized controlled trial design and showed that there was actual further advancement of 25% at the A point and 15% at the P point in the horizontal plane during the eighth to twelfth postoperative weeks.¹⁹ As with the vertical movement of the A point, further downward movement of 15% during the second to eighth weeks and of 10% during the eighth to twelfth weeks was noted. This downward movement of the maxilla could be attributed to the use of elastic traction to control the occlusion during the consolidation period of distraction, when the regenerated callus remains malleable. Although similar elastic traction in an attempt to stabilize the occlusion was also applied to the conventional osteotomy group, further backward relapse of the osteotomy was noted, particularly more so in the first postoperative 3 months. Our preliminary trial comparing conventional osteotomy and distraction for CLP

was thus able to confirm differences in skeletal relapse between the two techniques. Still, a larger sample is needed to confirm this superiority of distraction over conventional orthognathic surgery in terms of stability.

Impact on Speech and Facial Esthetics

During maxillary advancement by Le Fort osteotomies, the soft palate is pulled forward, thereby increasing the anteroposterior distance from the posterior pharyngeal wall. These anatomic changes may adversely affect the velopharyngeal closure function and result in hypernasal speech and nasal air emission. Functional adaptation to these changes is harder for patients with CLP than for others because of their inherent velopharyngeal closure problems and the effects of the palatal scar. However, the evidence on this point is still controversial. Several reports have concluded that maxillary advancement has no real adverse effect on the speech of patients with CLP.^{1,20} Others have described deterioration in both velopharyngeal closure and speech after maxillary advancement.^{21–23} Witzel and Munro evaluated velopharyngeal closure in 50 patients with CLP after Le Fort I advancement and found no change in patients whose velopharyngeal closure had been judged to be adequate or inadequate; however, 11 of 15 patients with borderline velopharyngeal closure showed symptomatic velopharyngeal insufficiency after the operation.²² The researchers concluded that particular care must be taken when treating patients with borderline preoperative velopharyngeal closure. As far as the cases considered in our meta-analysis are concerned, most patients assessed after conventional osteotomy showed no change in velopharyngeal function (80%), speech (87.76%), or articulation (90%). Although there was an increase in hypernasality (80%), nasal emission and resonance were mild and inconsistent (40%). These findings are suggestive of a difference, but the sizes of these two groups are too small to enable a firm conclusion to be reached.

When distraction osteogenesis is successfully applied to correct maxillary hypoplasia, the surrounding mucosal and muscular tissues may have a better chance to adapt to the skeletal changes through slow movement than through the sudden changes produced by conventional Le Fort I osteotomy. Guyette and colleagues presented their experiences on the changes in resonance, velopharyngeal function, and articulation following maxillary advancement by distraction osteogenesis.²⁴ Of a total of 18 patients with CLP, 3 (16.67%) experienced deterioration in hypernasality after maxillary distraction and 12 (67%) experienced an improvement in articulation. Ko and colleagues evaluated the anatomic changes revealed by lateral cephalographs of patients with CLP who underwent maxillary advancement by distraction osteogenesis.²⁵ These authors tested the correlation between the velopharyngeal changes and the degree of maxillary advancement, as measured by cephalometry and clinical speech evaluation. They found that a mean of 8.9 mm maxillary advancement resulted in deterioration of hypernasality among 14% of patients but an improvement in articulation among 57%. The researchers concluded that the deterioration of hypernasality was related to the amount of forward distraction, which is worst in patients without preexisting pharyngeal flaps.

No change in the velopharyngeal function was reported in any of the cases of cleft maxillary distraction considered in our meta-analysis; in the vast majority of cases (80.56%), there was no change in hypernasality either. Distraction was able to produce an improvement in nasal breathing (100%) and articulation (47.73%). We should be cautious, however, in drawing general conclusions from a comparison of qualitative data. The benefits of distraction osteogenesis in this respect still have to be confirmed by a properly designed randomized controlled study.

We are on much safer ground in comparing the contributions made by conventional osteotomy and distraction to an improvement in facial esthetics. According to the reports considered in our meta-analysis, both conventional osteotomy and distraction osteogenesis can result in substantial improvements in various measures of facial esthetics.

Choice of Distractor for Patients with CLP

Initially, distraction for patients with CLP entailed applying distraction to the maxillofacial region with the use of extraoral devices (Figure 49-1). The first extraoral distractor was developed in Germany and marketed by Normed Medizin-Technik GmbH, Tuttlingen, Germany and uses a skull frame containing transcutaneous pins on the nasal bridge and both zygomas. The problem

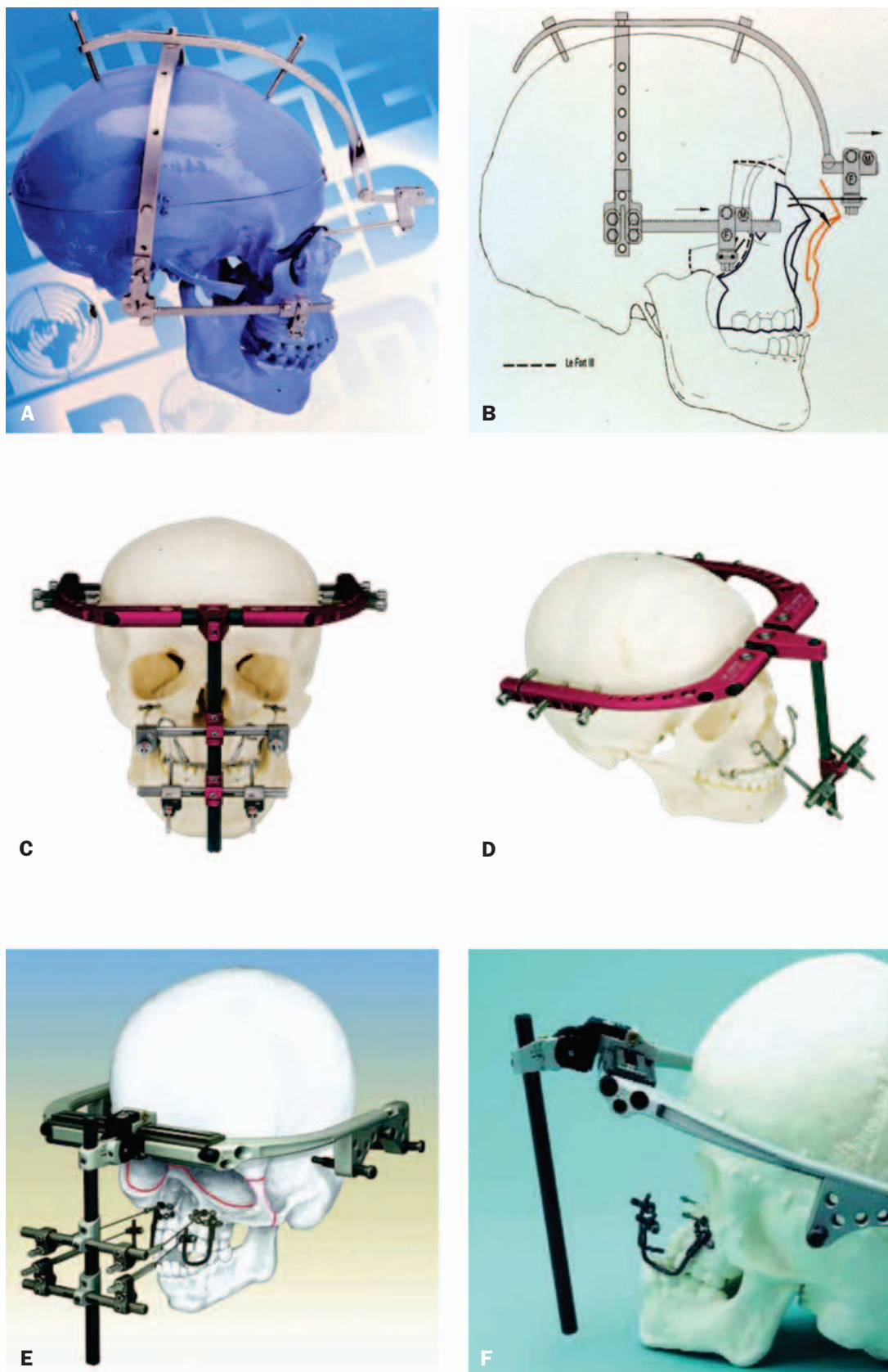


FIGURE 49-1 Examples of external maxillary and midface distractors. A and B, The Normed extraoral extractor is used primarily for Le Fort III distraction; C and D, the KLS Martin rigid external distractor (version II) uses a combination of tooth and bone anchorage for all types of Le Fort distraction; E and F, the Synthes external midface distractor can function as a KLS Martin's distractor with a difference in the skull pin pattern, the ability to make an angular adjustment of the vertical rod assembly.

of facial scarring on the conspicuous areas of the face prompted Polley and Figueroa to develop a tooth-borne fixation method by modifying the skull frame; the system is commonly known as the RED system, which stands for the rigid external distractor, and is marketed by KLS Martin L.P. (Jacksonville, FL). Further improvement was made in the BLUE system of Lorenz and the external midface distractor of Synthes (Synthes Maxillofacial, Paoli, PA), both of which enable the clinician to adjust the transverse skull dimensions and change the maxillary midline. Experience gained with extraoral distractors in various applications then paved the way for the development of intraoral devices. Extraoral devices are used more frequently than intraoral ones because of their ease of installation and removal and because the vector of distraction can be changed at any time during the distraction phase.^{26,27} A major drawback of extraoral devices, however, is scarring owing to traction and use of transcutaneous pins.²⁸ Furthermore, many patients consider extraoral devices to be socially inconvenient.²⁹

In another approach, which aimed at not pulling the cleft maxilla forward, distractors were designed to push the midface forward from behind using easily camouflaged transtemporal pins or rotary buttons (Figure 49-2). Subsequently, Molina designed a simple yet robust transtemporal distractor in which the distractor arm is engaged along the curve formed by the frontal process and the arch of the zygoma; this device is primarily indicated for Le Fort III or Kufner osteotomy. Cohen designed a distractor with a similar concept but mainly for pediatric patients and using micromesh as the fixation method. For adults, an internal midface distractor with modular attachments was developed by Synthes. KLS Martin, on the other hand, developed the Riediger midface distractor, which has a rotary button to minimize the interference of the activating rod when the patient lies down. Owing to the difficulty of removing the mesh, W. Lorenz Surgical (Jacksonville, FL) replaced the titanium mesh with bioresorbable mesh to obviate the removal of the fixation mesh; because only the metallic rod needs to be pulled out, this device minimizes the morbidity associated with distraction surgery at the removal stage.

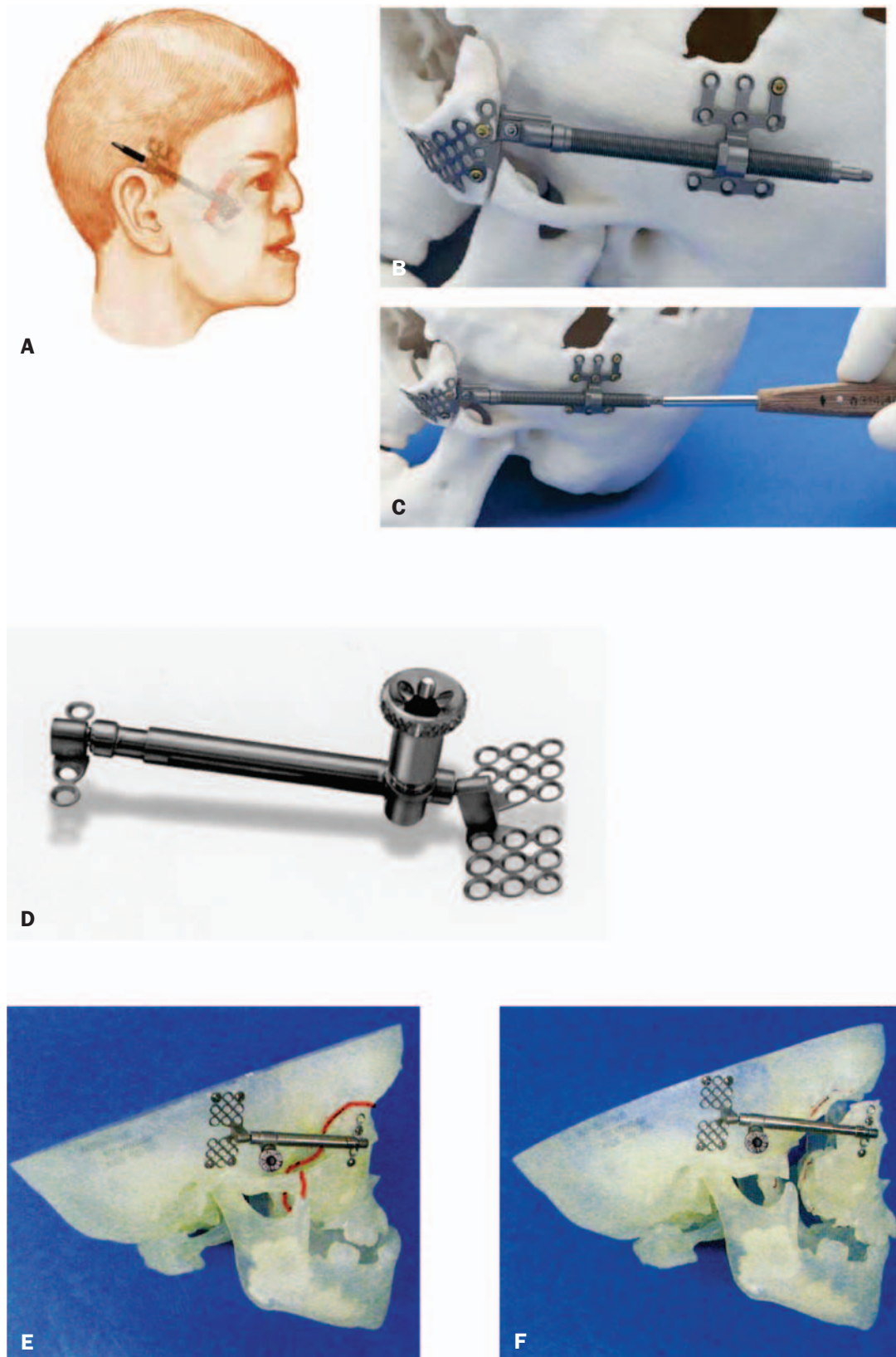


FIGURE 49-2 Samples of transtemporal midface distractors. A to C, The Synthes internal midface distractor is used for activation by the temporal approach and fixation over the zygoma with mesh and squamous temporal bone with miniplates; D to F, the Riediger midface distractor has similar fixation locations, but the mesh is for temporal fixation, whereas a straight plate is for lateral orbital rim fixation. The innovative design of activation by a rotating knob minimizes discomfort during sleep when compared with a design with rod extrusion behind the ears.

Only a few designs of intraoral distractor are available to allow correction of maxillary deformities (Figure 49-3). KLS Martin was the first to produce such a device—the Zürich pediatric maxillary intraoral distractor. However, the use of low-profile screws 1.5 mm long hinders the ability of this distractor to overcome the large tensional forces commonly encountered in patients with CLP. Synthes addressed this problem by developing a modular intraoral distractor using 2 mm screws, which was able to distract the maxilla by as much as 25 mm. An ingenious distractor design that uses the maxillary sinus to hide the distractor was marketed by KLS Martin as the Nadjmi Trans-sinusoidal Maxillary Distractor. The disadvantage of this design is that the anatomic configuration of the sinus can limit the length of distractor used and the subsequent range of movement. The advantages of these devices over extraoral ones are that they are less conspicuous and present a more acceptable mode of treatment to both patients and parents. Still, the insertion of intraoral devices is more complicated than extraoral ones because of the complex maxillary anatomy. The successful application of intraoral maxillary distractors depends on the bone being strong enough to anchor the device to the zygomatic buttress. In addition, bone in the dentoalveolus of the mobilized maxillary segment needs to be sufficiently thick to anchor the lower fixation arm without damaging the maxillary teeth. When the maxilla is advanced to the predetermined position, it is very important to place the distractors parallel to each other, on either side of the maxilla. Once the intraoral distractors are positioned, the vector cannot be changed.⁴ Hence, the precision of the distractor orientation is vital to the final skeletal and occlusal results.

Vector Control of Maxillary and Midface Distraction

Vector control is the key factor in the transport of the cleft maxilla to the position representing the best occlusion and esthetic balance. It is relatively simple for the external midface distractor to exert three-dimensional control through the use of the extension arms. By activating the horizontal rod assembly, the maxilla can be pulled forward, whereas the tilting of the vertical rod assembly can move the anterior maxilla in an upward or downward direction. The maxillary midline can be adjusted transversely by turning the vertical rod assembly either to the right or the left. The external distractor can control the anterior maxillary movement quite well, but it cannot control the posterior maxilla, which tends to come down too far and result in an anterior open bite. In compensating this problem, the anterior maxilla may be pulled downward, but this results in vertical maxillary excess. If there is an existing

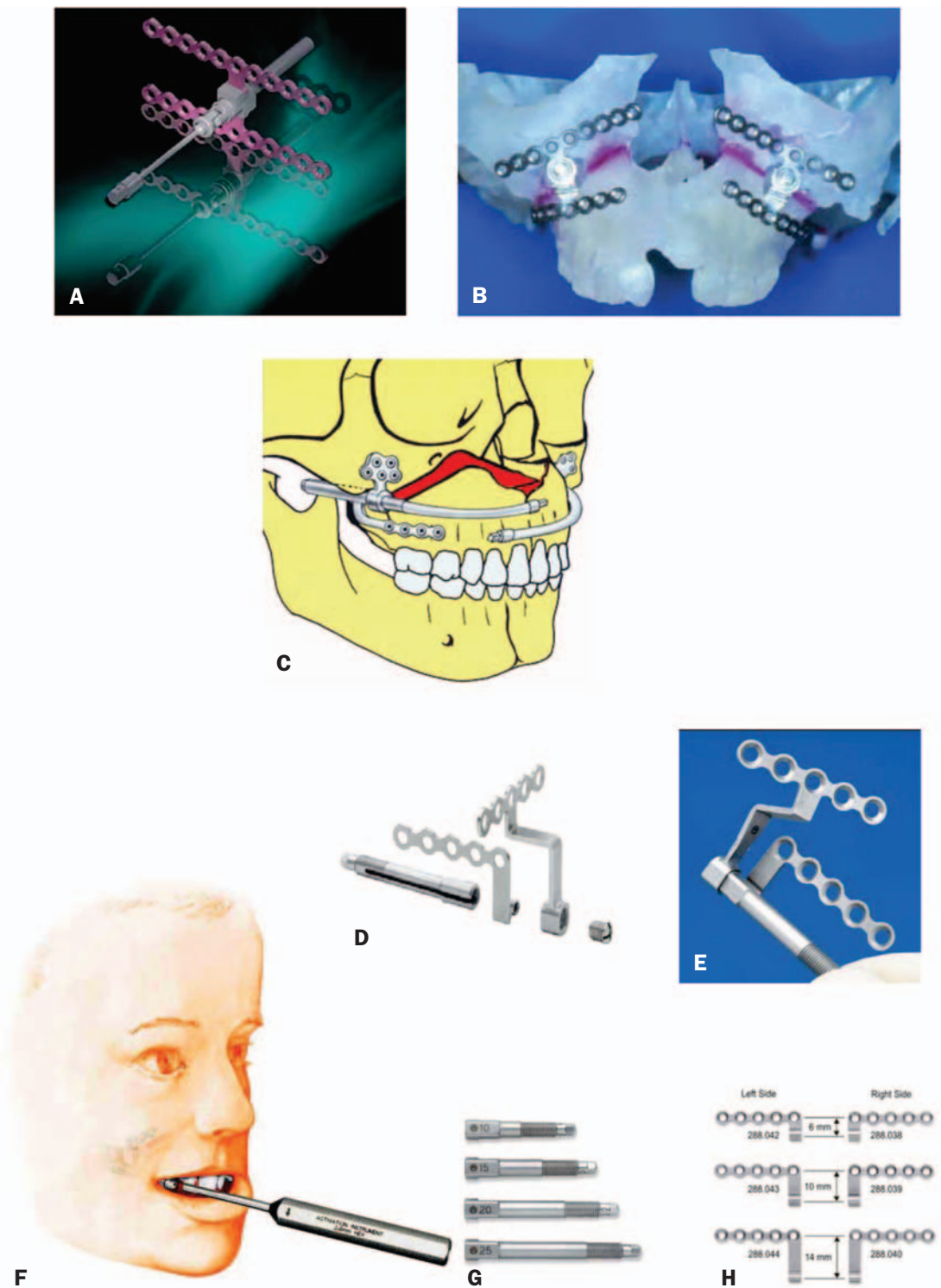


FIGURE 49-3 Samples of intraoral distractors for Le Fort I distraction. *A* and *B*, The Nadjmi Trans-sinusoidal Maxillary Distractor uses the maxillary sinus to hide the distractor body and the activating rod via the buccal mucosa; *C*, the KLS Martin Zürich pediatric maxillary distractor has fixation on the zygoma and the maxillary alveolus and activation is controlled by a flexible rod that is easily concealed along the buccal sulcus; *D* to *H*, the Synthes intraoral maxillary distractor has the versatility of a modular design and fits into a wide range of distractor bodies from 10 to 25 mm in length, as well as different combinations of posterior and anterior footplates.

open bite, the recommended procedure is for the maxilla to be downfractured and the posterior segment to be impacted before activation because the vector cannot impact the maxilla beyond its original vertical position. Overall, the external distractor can provide effective multivector control of the anterior maxilla, and bone-borne attachments are preferred over tooth-borne ones for a more secure delivery of the vector force.

In contrast, internal maxillary or midface distractors can exert only bidirectional vector control in a forward and downward direction. The extent of the transverse change of the maxillary midline is limited if a distractor is activated more on one side than the other. Preoperative planning is the key factor in determining the success of the desired occlusion and the amount of incisal exposure because once the currently available midface distractors are impacted, they cannot alter the vector afterward as external distractors can. To ensure that the maxilla translates anteriorly in a smooth manner, the distraction path must be unobstructed. In addition, the distractor rods must be oriented parallel to the distraction vector. Therefore, a vector guidance splint is needed to improve the accuracy of distraction.

Nakagawa and colleagues developed a device for determining the position of a Zürich pediatric maxillary distractor.³⁰ The device is composed mainly of Roger Anderson pins that are arranged in a rectangular configuration to allow both cylindrical distraction activators to be positioned parallel to each other. Intraoperatively, the interpupillary line and Frankfort horizontal plane are used as reference lines for the osteotomy and device placement, and anesthetists usually demand that the eyelids be taped to prevent accidental corneal abrasion. Unfortunately, the Frankfort horizontal plane is very variable and lacks precision.

We developed a method of manufacturing a vector guidance splint for intraoral maxillary distraction³¹ on the basis of our experience of orthognathic surgery planning (Figure 49-4). The actual vector control of distraction correlated well with the planned direction of movement, and excellent results have been achieved.

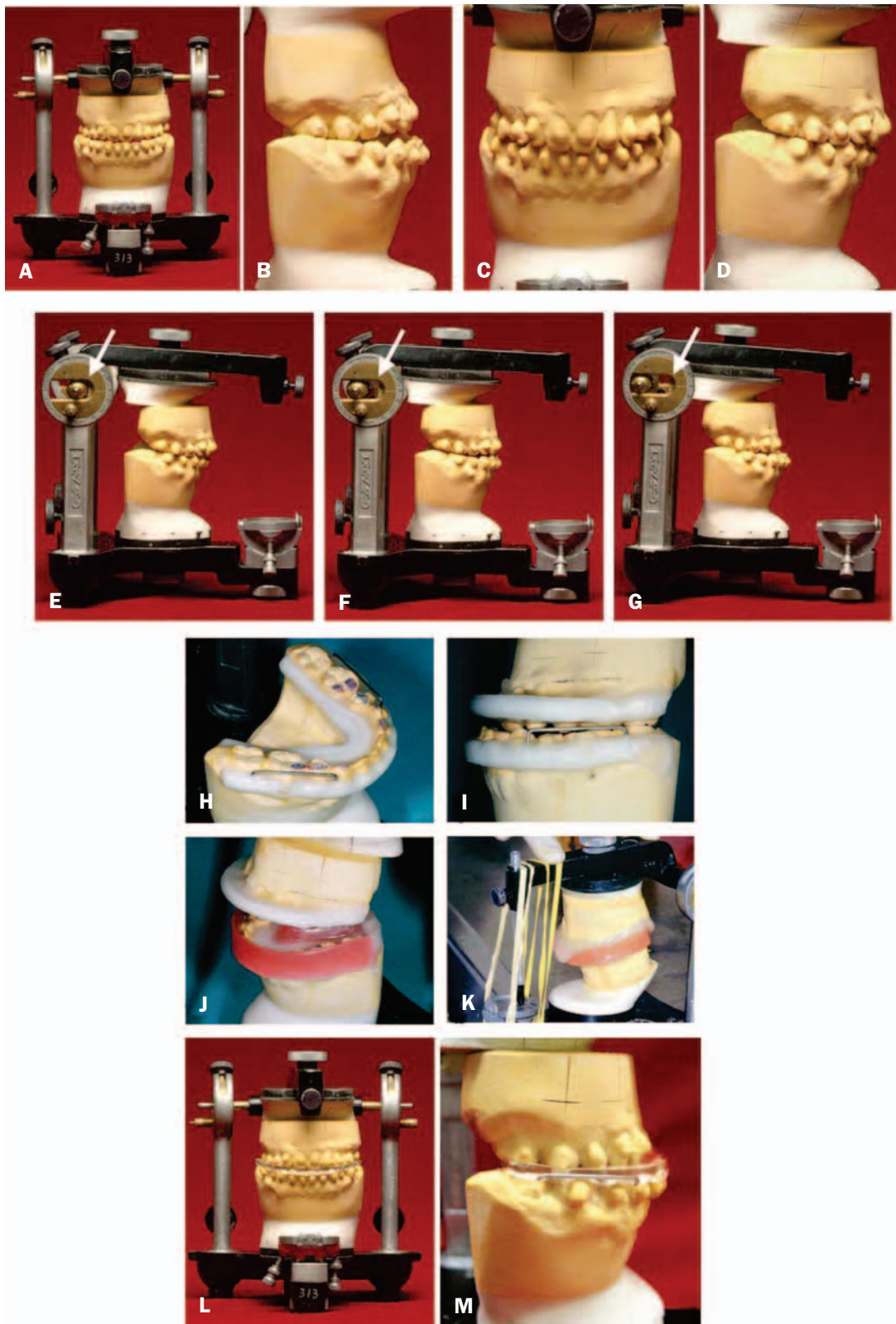


FIGURE 49-4 Model surgery and fabrication process of the vector guidance occlusal splint. A to D, Advancement of the maxilla mounted on a Hanau articulator; E to G, setting back of the advanced maxilla by release of the condyle locking screws on both sides, in preparation for vector splint fabrication; H to K, laboratory fabrication process with wax boxing and embedment of a guidance wire; L to M, the completed vector guidance splint is relocated in the model before delivery to the operating table.

Other available methodologies to determine the path of maxillary distraction include preadaptation of distractors on a stereomodel and surgical navigation. It is noteworthy that computed tomography is necessary in both techniques, and this increases patients' exposure to radiation. Stereomodels, although costly, are useful in managing complicated craniofacial deformities, in teaching about prebending of distractors, and in demonstrating distractor movement (Figure 49-5). Surgical navigation can simulate the maxillary distraction vector,³² but the preparation time needed for intraoperative navigation prolongs surgery and patients' duration of anesthetic exposure.

Surgical Techniques of Cleft Maxillary and Midface Distraction

Surgical techniques of distraction for patients with CLP depend on the location and extent of the maxillary or midfacial deformities.

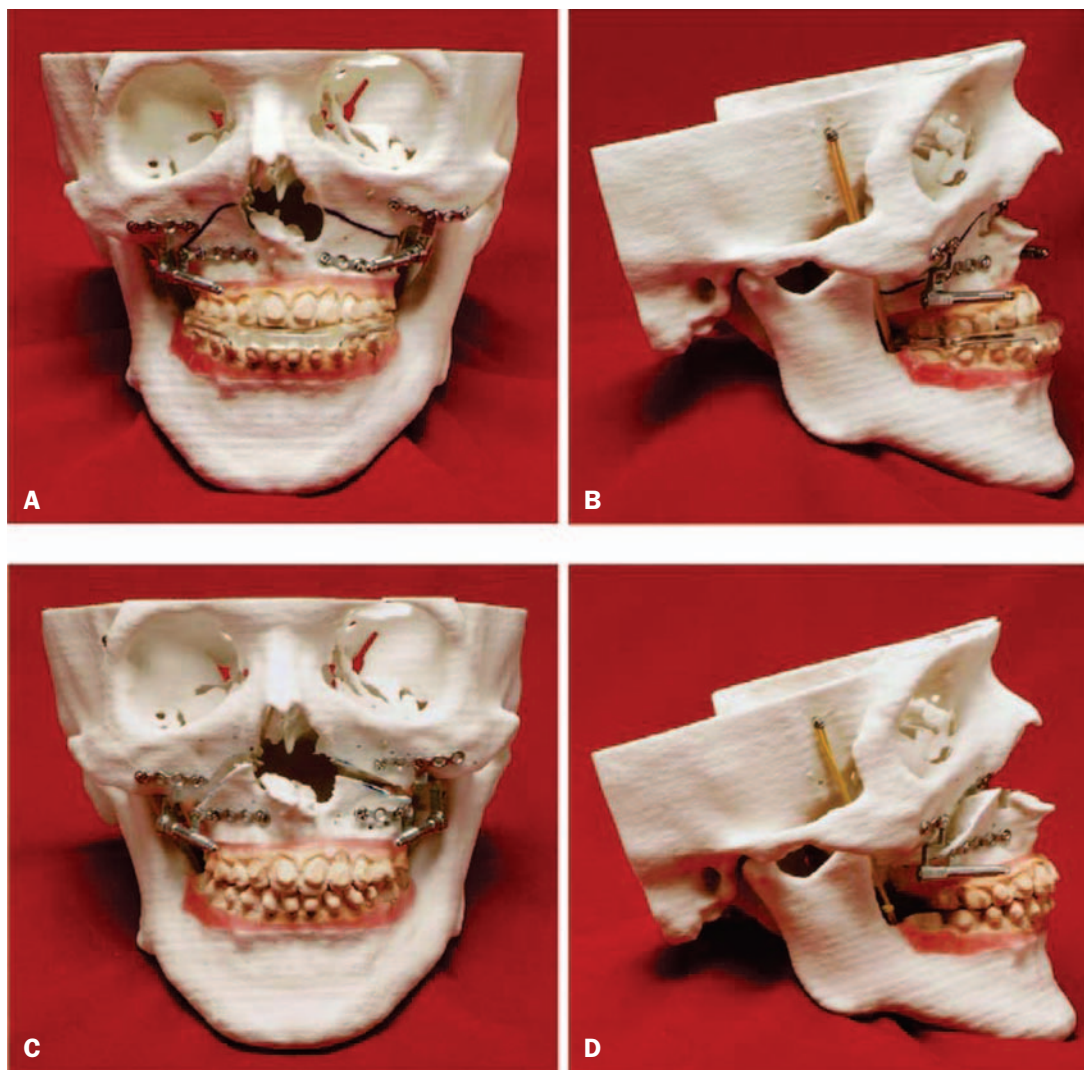


FIGURE 49-5 Simulation of Le Fort I maxillary distraction on a stereomodel *A* and *B*, Synthes distractors are adapted on both sides, and the Le Fort I cut is marked with the occlusion fitted to a vector guidance splint; *C* and *D*, distraction movement is simulated by activating the distractors to achieve the desired occlusion.

In low-level maxillary hypoplasia, Le Fort I osteotomy can be distracted effectively by either intraoral or external distractors. Patients with unilateral CLP who present with low-level maxillary hypoplasia and concomitant mandibular deformities can be treated by distraction of the maxilla combined with conventional orthognathic surgery of the mandible (Figure 49-6).

In nasomaxillary hypoplasia, Le Fort II osteotomy is indicated for correction. The Le Fort II segment can also be effectively transported forward and downward by either an intraoral or an external distractor. Patients undergoing correction by Le Fort II osteotomy with intraoral

distractors can achieve a pleasing outcome (Figure 49-7).

In high-level maxillary hypoplasia, Le Fort III osteotomy is indicated if the whole midface requires distraction. If the nasal prominence is normal, a Kufner osteotomy can be performed for effective movement of the maxilla and zygomas without moving the nose. We treated a patient with zygomaticomaxillary hypoplasia and mandibular asymmetry by performing Kufner osteotomies with internal midface distractors (Figure 49-8). The aim was to correct the mandibular asymmetry at the time of distractor removal; hence, midface distraction moved the

maxilla only to the predetermined position while leaving the mandible to be set back and rotated later.

The techniques of applying the internal maxillary distractor, external midface distractor, and transtemporal distractor are further elaborated below.

Distraction with the Internal Maxillary Distractor

The surgical sequence of applying the internal maxillary distractor during Le Fort I osteotomy is illustrated in Figure 49-9.

A continuous maxillary incision of 5 mm is made above the mucogingival margin from the right first molar to the left first molar. The buccal tissue is reflected to expose the bony alveolus and zygoma. An intraoral bone-borne maxillary distractor (from Synthes) is bent and fitted to the maxillary alveolus and the zygomatic buttress. The distractor rod is then oriented to parallel the vector guidance splint. The distractor is fixed temporarily with one screw at the posterior footplate. The planned buccal cut of the Le Fort I osteotomy is marked out to ensure clearance from the two distractor footplates. Thereafter, the distractors are removed and a standard Le Fort I osteotomy is performed.³³ The buccal osteotomy is completed anteriorly from the piriform rim to reach the pterygomaxillary junction posteriorly. The nasal septum is transacted at its base by a forked osteotome, and the tuberosities of both sides are osteotomized.³⁴

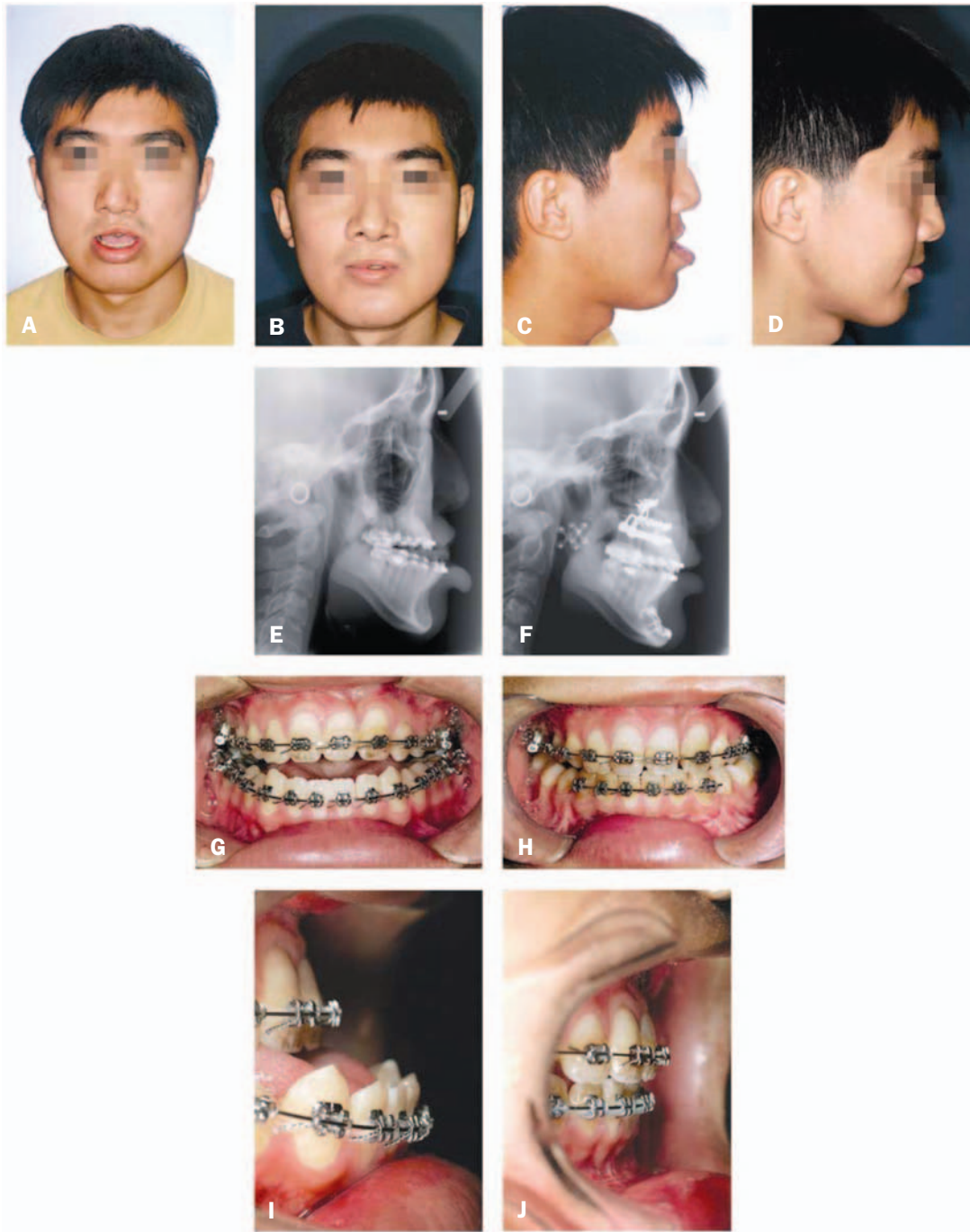


FIGURE 49-6 Treatment of a patient with unilateral cleft lip and palate by Le Fort I distraction using intraoral distractors. A and C, Presurgical frontal and side views; B and D, postsurgical frontal and side views showing a more balanced appearance; E and F, lateral cephalographs before and after active distraction; G to J, occlusion and overjet before and after the distraction.

Next, the maxilla is downfractured with finger pressure and fully mobilized but not transposed to the final occlusal position. The maxillary sinus walls and nasal septum are then excised according to the model surgery. Any maxillary segmentalization is performed according to the presurgical plan. The teeth of the maxilla are fitted to the vector guidance splint, and the arch bars are ligated to both the maxillary and mandibular teeth, which then undergo intermaxillary fixation with the vector guidance splint sandwiched between. The maxillary vertical markings are checked to ensure adequate removal of intervening bone and to maintain good contact of the buccal bone between the fragments. The distractors are reinserted in their predetermined positions so that the distractor body on either side is parallel to the wire orientation in the vector guidance splint. An extension rod fitted to the end of the distractor body is useful to check the convergence angle of both maxillary distractors. The distractors are adjusted to parallel each other sagittally if a large amount of maxillary distraction is planned. A small convergence angle is acceptable only if a moderate amount of maxillary distraction is planned; otherwise, the screws may dislodge during extensive advancement.

Once the distractors are fixed in their three-dimensional orientation, intermaxillary fixation is cut and the vector guidance splint is removed. The distractors on either side are activated for a few millimeters to check the correctness of maxillary transport, with the aim of reaching good interdigitation during occlusion. The mucosal wound is then closed by continuous suturing to leave the distractor rod outside the wound for later activation with a distraction key.

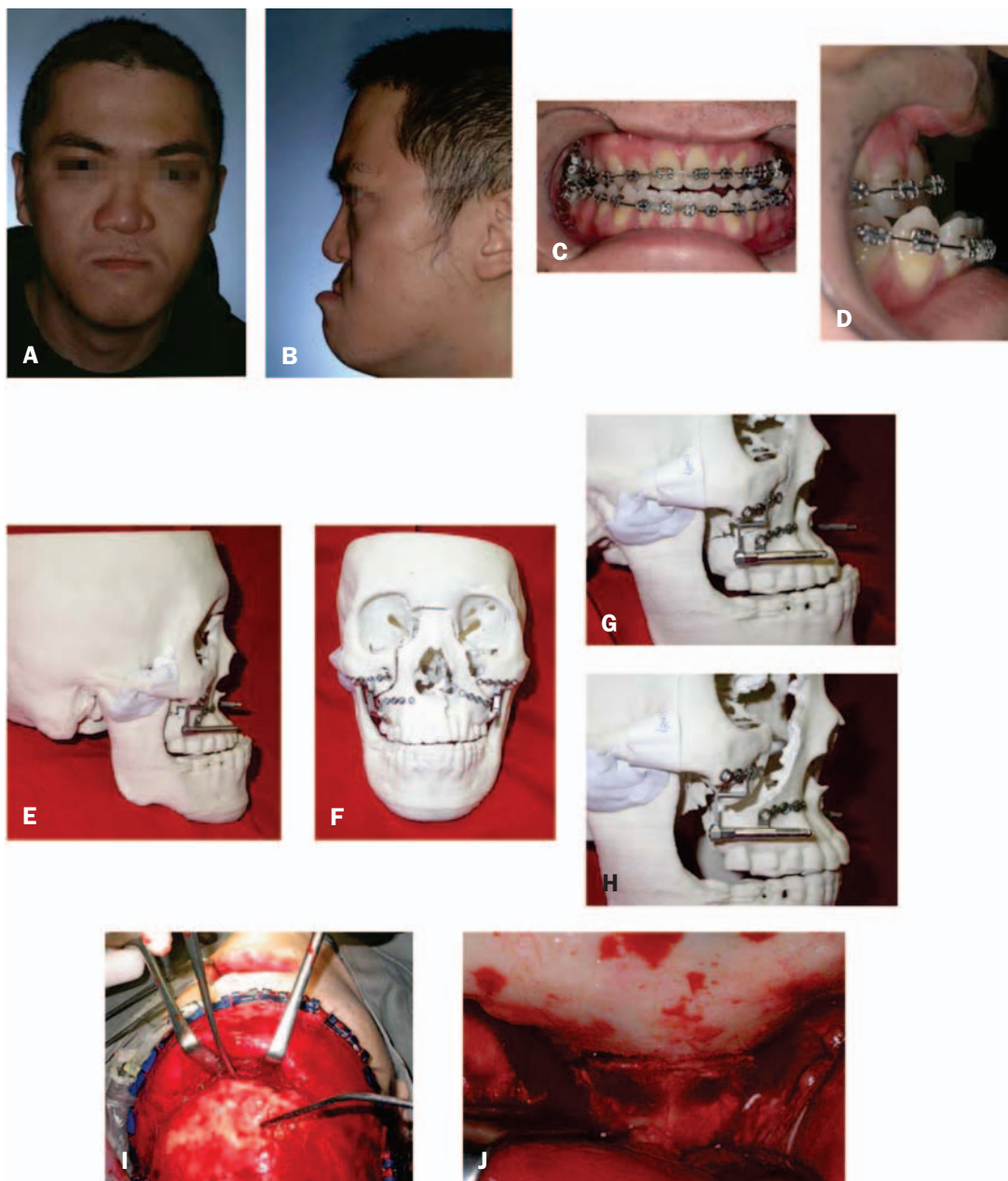


FIGURE 49-7 Treatment of a patient with unilateral cleft lip and palate who presented with nasomaxillary hypoplasia by Le Fort II distraction with intraoral distractors. A to D, Classic facial appearance of nasomaxillary hypoplasia showing that the occlusion was aligned and decompensated by orthodontics; E to H, stereomodel simulation of Le Fort II osteotomy by preadaptation of Synthes intraoral maxillary distractors;

Distraction by External Midface Distractor

The surgical techniques of maxillary downfracture and change in the occlusal plane using the vector guidance splint are essentially the same as for the internal distractor protocol. The Synthes external midface distractor is used to illustrate the technique of applying external maxillary distraction.

The maxillary foot is adapted over the maxillary alveolus of the maxillary segment at the

canine premolar region on each side. The maxillary rod is then bent to adapt to the lip level so that it will not interfere with the lip competence. The maxillary footplates of each side are secured with screws of 8 to 10 mm in length and preferably of 2 mm in diameter, which have to be tightened well so that they do not get dislodged during the maxillary distraction movement.

The headframe is placed over the skull, and the width of the frame is adjusted to minimize interference with the lateral orbital bone. One

position screw is inserted into the center hole of the mounting plate assembly of the headframe. The frame is then placed with at least 2 cm clearance in front and above the supraorbital rim or more if the patient normally wears glasses. The frame is preferably oriented to be parallel to the Frankfort horizontal plane. The frame should be set at the midfacial midline, and the surgeon should stand behind the patient's skull for a better view of the symmetry of the frame placement. The position screw on each side is then tightened over the squamous temporal bone. After the orientation of the headframe is confirmed to be correct, three mounting pins are threaded into each headframe assembly, preferably in a radial or tripod pattern for maximal three-dimensional stability. The mounting pins should be finger-tightened with the adjustment instrument until they are secured on the hard cortical bone. Overtightening should be avoided because the pins may penetrate into the skull, especially in young patients. The frame is checked for its stability by gentle rocking, and any looseness should be further tightened.

The vertical assembly is slid along the dovetail of the central hub on the headframe assembly. If possible, the vertical rod should point vertically downward because patients tend to have a flatter nasal tip than others. The horizontal rod assembly is then slid from the base of the central rod of the vertical assembly to the level of the maxillary rods. One horizontal rod is sufficient for Le Fort I and II procedures, whereas two rods are required for Le Fort III and monobloc procedures. Stainless steel wires are then twisted to connect the horizontal rod with the maxillary rod assembly to deliver the distraction force.



FIGURE 49-7 continued. *I* to *L*, surgical access by the coronal flap for the nasal and orbital cuts and oral access for the maxillary cuts; *M* and *N*, fixation of the preadapted distractors; *O* and *P*, Le Fort II segment satisfactorily distracted to the preplanned position; *Q* to *T*, good postoperative facial balance and stable occlusion at 3 years.

Distraction by Transtemporal Distractor

The placement of the internal midface or trans-temporal distractor is primarily indicated for Le Fort III and Kufner osteotomies. The surgical procedure would ideally be planned with a stereo-model that preadapts the pair of distractors over the zygomatic bones on each side. That configuration would allow a more accurate simulation of the midface to be achieved, and one or more vector guidance splints could then be prepared on the basis of the frontozygomatic locations of the distractor. This protocol will minimize any error in the placement and angulation of the distractors and their ultimate distraction outcomes.

The surgical approach is normally done via a coronal flap to expose the lateral orbital rim for Kufner osteotomy and the nasal bone for Le Fort III osteotomy. The distractor is then temporarily located with one hole on the anterior footplate and one hole on the posterior footplate. Ideally, the anterior footplate is located on the zygomatic bone and the posterior footplate is located on the squamous temporal bone. Reflection of the temporalis muscle should be avoided, and dissection over the temporal region occurs preferably just above the deep temporal fascia.



FIGURE 49-8 Treatment of a patient with unilateral cleft lip and palate who presented with zygomaticomaxillary hypoplasia and asymmetric mandibular hyperplasia. A to C, Classic facial appearance and lateral cephalographs showing flattening of the zygomatic prominence and paranasal depression and concomitant mandibular asymmetric protrusion; D to F, adaptation of transtemporal distractors on a stereomodel for distraction during Kufner osteotomy; G and H, intraoperative view of the placement of distractors; I to K, postdistraction appearance and cephalographs showing a normal prominence of the zygomaticomaxillary complex without an increase in nasal prominence. Treatment of mandibular asymmetry was planned for a second surgery.

The osteotomy is performed according to the osteotomy type, and the midface is mobilized by Rowe disimpaction forceps. The distractors are then relocated to the preplanned position, and the screws are replaced and additional screws added. A trial distraction should be done to demonstrate that the distractors can overcome the tension and move the midface forward smoothly. Otherwise, the distractors need to be removed and the midface further mobilized. The coronal flap can be replaced, and the distractors can be vaguely seen below the temporal skin. The activation can start on the third day until the midface reaches a satisfactory prominence and normal occlusion.

Conclusion

Distraction osteogenesis of the maxilla or midface is gaining recognition as the treatment of choice for maxillofacial hypoplasia in patients with CLP. A wide range of maxillary and midface distractors of external, transtemporal, or internal designs are now available. Selection of the type of distractor for a specific patient depends on factors such as the type of osteotomy to be performed, the extent and complexity of movement, the experience of the surgeons, and patients' concerns about social convenience. The placement techniques of the three main designs of distractors have been well defined, and vector control is most important in achieving good results. Above all, surgeons need to plan correctly and execute precisely to gain the best outcome.

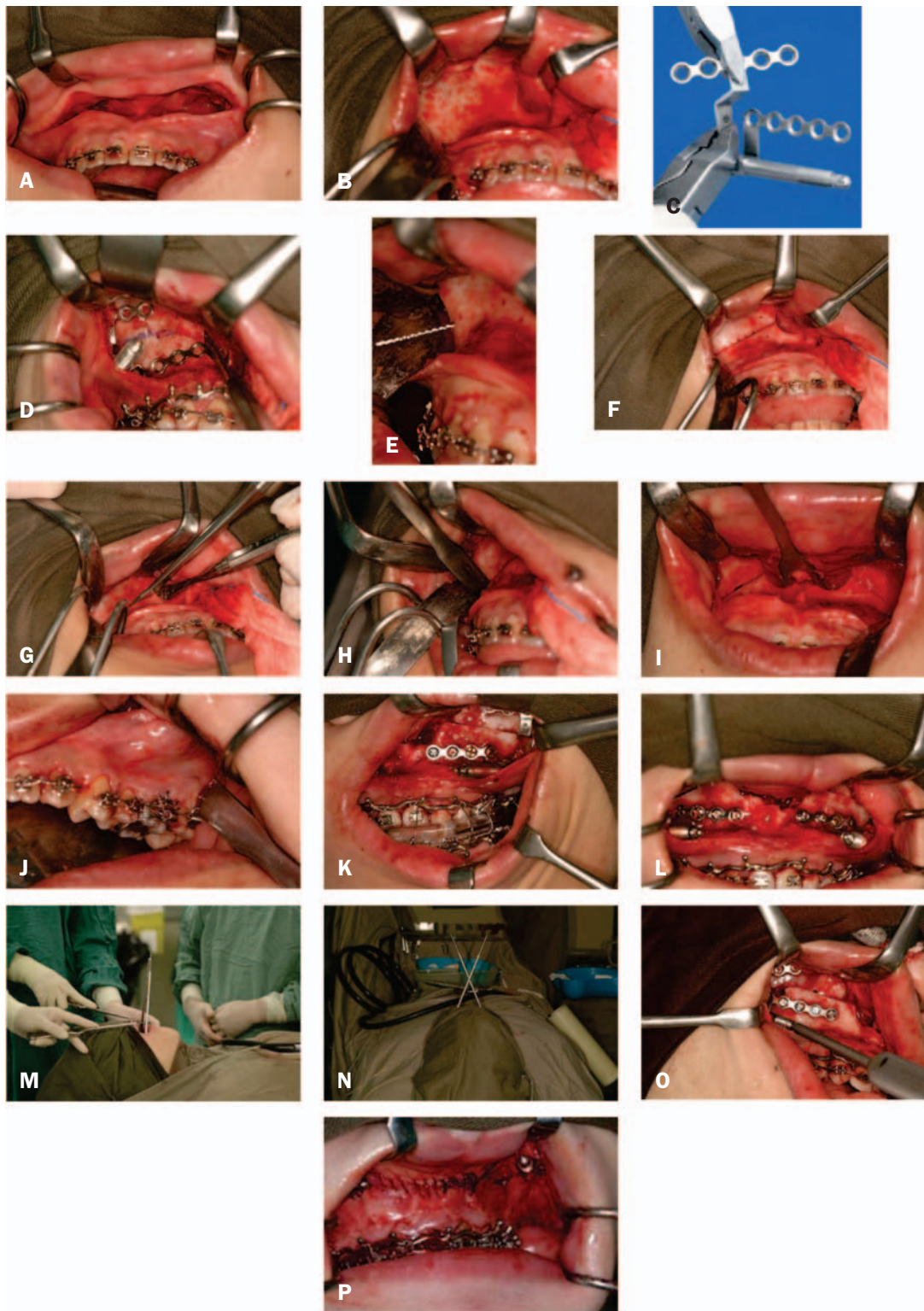


FIGURE 49-9 Surgical sequence of placement of Synthes intraoral maxillary distractors for Le Fort I distraction. A, The buccal mucosa is incised from first molar to first molar; B, the maxilla is exposed up to the infraorbital nerve level; C, the distractor is bent at the posterior footplate; D, the distractor is adapted to the maxilla and the osteotomy is drawn into the space between the two footplates; E and F, osteotomy is conducted with a reciprocating saw at the tuberosity and the Le Fort I cut is completed; G and H, completion of the cut by osteotome; I, nasal septal separation is performed with a forked osteotome; J, posterior osteotomy is done via the tuberosity with an osteotome; K and L, distractors are placed parallel to the wire in the vector guidance splint; M and N, distractor convergence is confirmed with the use of alignment rods; O, trial activation confirms that there is no obstruction of distraction movement; P, primary wound closure leaves the distractor tip exposed in the sulcus for activation.

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Reconstruction of Acquired Segmental Defects of the Mandible in the Age of Distraction Osteogenesis: Guide to Clinical Decision Making

R. Bryan Bell, Eric J. Dierks and Jason K. Potter

The loss of mandibular continuity as a result of ablative tumor therapy or severe trauma is physiologically and psychologically debilitating (Figure 50-1). The goals of mandibular reconstruction are the restoration of appearance, mastication, deglutition, speech, and oral competence. The technique used to achieve these goals is

largely dependent on the complexity and size of the congenital, developmental, or acquired defect, as well as the surgeon's training, experience, and specialty. A number of patient-, procedure-, and disease-related factors must be considered when attempting reconstruction of these challenging clinical problems. The purpose of this chapter is

to provide the reader with a literature-based guide to clinical decision making for various acquired segmental mandibular defects.

Historical Perspectives

As of the time of this writing, a *Medline* query for reconstruction of the mandible yielded almost 3,000 scientific articles. Indeed, the medical literature has collected articles detailing advances in mandibular reconstruction for centuries.¹ The modern science of mandibular grafting, however, began in the early parts of the nineteenth and twentieth centuries with such notable works as those by Ollier,² Macewen,³ and Skyhoff.⁴ Prior to this, patients with facial injuries often died, the deformities were ignored, and continuity defects of the mandible were simply allowed to collapse on themselves. During the great wars of the twentieth century, physicians and dentists began to recognize the importance of oromandibular rehabilitation. Experiences in World War I and World War II resulted in unprecedented advances in maxillofacial reconstructive surgery, such as the use of nonvascularized bone grafts, interdental wire fixation, skin grafts, and "tubed" pedicled soft tissue flaps, as advocated by Lindemann,⁵ Morestin,⁶ Delageniere,⁷ Blair and Ivy,⁸ Blair,⁹⁻¹¹ Ivy,¹²⁻¹⁴ Filatov,¹⁵ Gillies,¹⁶⁻¹⁸ Gillies and Millard,¹⁹ Pichler,^{20,21} Sonntag,²² Wassmund,²³ Reichenbach,²⁴ Kazanjian,²⁵⁻²⁷ Kazanjian and Converse,²⁸ Converse,²⁹⁻³³ Converse and Rapaport,³⁴ Mowlem,^{35,36} Blocker and Weiss,³⁷ Ullik,³⁸ and Smith.^{39,40} By the end of World War II, advances in surgical technique, advances in anesthesiology, and the advent of penicillin led to improvements in morbidity and mortality and made reconstructive surgery a common reality. Iliac crest cortical and corticocancellous bone grafts had largely

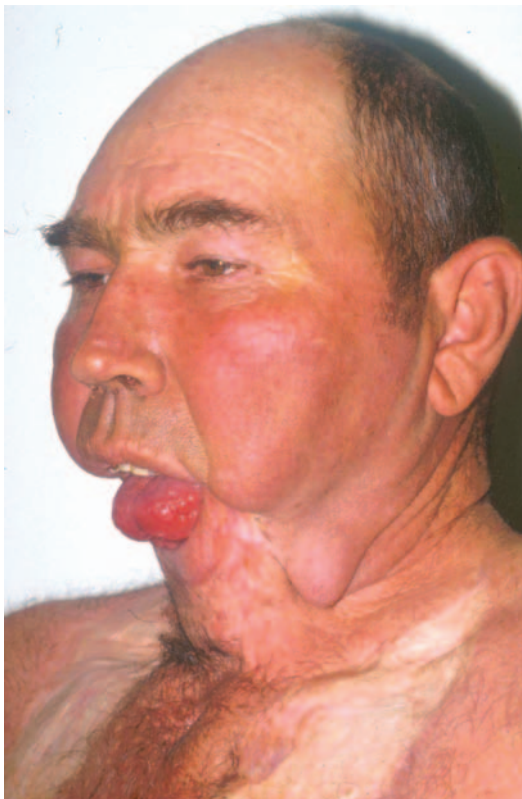


FIGURE 50-1 "Andy Gump" deformity. The patient underwent surgery for advanced-stage cancer of the anterior floor of the mouth, including a composite resection of the anterior floor of the mouth and mandible and failed reconstruction. The deformity is severely disfiguring and resulted in oral incompetence, dysarthria, dysphagia, and gastrostomy tube dependence.

supplanted tibial bone grafts as the reconstructive modality of choice for mandibular continuity defects, and the importance of graft bed soft tissue preparation was recognized. Early techniques to bring nontraumatized regional soft tissues to improve vascularity and soft tissue stability of the scarred wound bed began by using random-pattern “tube” grafts to create a “sausage of soft tissue with bone in the middle.”¹⁹ Although the principle of graft stability was already understood, the materials to achieve this were relatively crude and limited to the use of plaster head frames, interdental wire fixation, and external pin fixation. Further advances were made during the Korean War and the Vietnam conflict, as described by Conley,⁴¹ Trauner,⁴² Obwegeser,^{43,44} Rowe,⁴⁵ Rowe and Killey,⁴⁶ Rowe and Williams,⁴⁷ Manchester,^{48,49} Boyne,⁵⁰ Boyne and Zarem,⁵¹ Bromberg and colleagues,⁵² Bakamjian,⁵³ and Luhr.⁵⁴ Following the Vietnam era, the ensuing and relatively peaceful three decades witnessed significantly fewer cases of severe maxillofacial trauma. Major improvements in maxillomandibular reconstruction continued during this time as ablative surgical techniques for head and neck malignancy advanced. Although cancer survival rates from head and neck malignancies have only marginally improved over the last 50 years, advances in reconstructive surgical techniques have significantly improved the quality of life (QOL) for patients after ablative surgery by minimizing the functional and cosmetic sequelae of treatment. McGregor and Jackson’s description of the groin flap⁵⁵ ushered in the era of regional axial pattern flaps. Ariyan was first to recognize the versatility of the pectoralis major myocutaneous flap in head and neck reconstruction, and it quickly became the “workhorse” soft tissue flap of the 1980s.⁵⁶ Also during this time, Marx popularized the use of the pectoralis major flap combined with large-volume iliac crest bone grafts to reconstruct a wide variety of segmental mandibular defects and reported improved outcomes with adjunctive measures such as the use of hyperbaric oxygen (HBO).^{57,58} Interestingly, the technique of using axial pattern flaps combined with nonvascularized bone grafts for mandibular reconstruction was paralleled by the development of microvascular free tissue transfer, made possible by the introduction of the operating microscope and specialized instrumentation by Jacobson and Suarez.⁵⁹ Following McGregor and Jackson’s description of an axial flap based on the superficial circumflex iliac artery (the groin flap) in 1972,⁵⁵ Taylor became the first surgeon to successfully divide the pedicle and transfer the groin flap as free tissue.⁶⁰ Advances in the understanding of perfusional anatomy led to the description of the “angiosome” concept by Taylor and Palmer in 1987⁶¹ and the further refinement in instrumentation and technique. Other surgeons,

such as Ueba and Fujikawa,⁶² O’Brien and Morrison,⁶³ Gilbert,⁶⁴ Chen and Yan,⁶⁵ Hidalgo,⁶⁶ Yang and colleagues,⁶⁷ Goufan and Baogui,⁶⁸ Muhlbaier and colleagues,⁶⁹ Soutar and colleagues,⁷⁰ Drever,⁷¹ dos Santos,⁷² Nassif and colleagues,⁷³ and Maxwell and colleagues,⁷⁴ made important contributions during the 1970s and 1980s by describing various free flaps based on the radial artery (radial forearm flap), peroneal artery (fibular flap), deep inferior epigastric artery (rectus abdominis flap), circumflex scapular artery (scapular flap), thoracodorsal artery (latissimus dorsi flap), and deep circumflex iliac artery (iliac crest flap). Schusterman and colleagues,^{75–77} Urken and colleagues,^{78–82} Hidalgo,^{83,84} Hidalgo and Rekow,⁸⁵ Cordeiro and Hidalgo,⁸⁶ Hidalgo and Pusic,⁸⁷ Wei and colleagues,^{88–90} Vaughan,^{91,92} and Schliephake and colleagues⁹³ should also be credited with popularizing microvascular free flaps for mandibular reconstruction, refining the techniques, and describing outcomes. For practical reasons, the fibular osteocutaneous flap and the radial forearm fasciocutaneous flap (RFFF) emerged as the dominant flaps for mandibular reconstruction during the 1990s and the beginning of the twenty-first century. Finally, the introduction of distraction osteogenesis,⁵⁵ and its subsequent application to the craniofacial skeleton,^{94–96} has provided another tool in the diverse armamentarium of reconstructive options for surgeons managing patients with a variety of congenital, developmental, or acquired defects of the facial skeleton.

Patient-Related Considerations

Classification of Segmental Mandibular Defects

Complex classification schemes for segmental mandibular defects have been proposed based on various bony, soft tissue, and neurologic deficits.⁹⁷ We prefer a simplified classification based on the position of the defect relative to the mandibular anatomy. This scheme divides the mandible into functional segments beginning in the midline with the symphysis (anterior) unit, the body (lateral) unit, the ramus-condyle (posterior) unit, and the alveolus. Each of these sites has variable physiologic factors that result in different functional deficits when lost as a result of tumor ablation or traumatic disruption. Consequently, reconstruction of each anatomic unit demands an individualized approach based on factors related to the patient, the reconstructive procedure, and the disease process.

Diagnostic Considerations

A number of important diagnostic or patient factors have been shown to affect the outcome of patients undergoing reconstruction for extirpative defects of the head and neck. These factors include the use of tobacco or alcohol, the

presence of medical comorbidities, nutritional status, and age.

Tobacco alone or in combination with alcohol has been shown to be an important etiologic factor in the development of oral and oropharyngeal cancers. It has been demonstrated that patients who smoke tobacco are at increased risk of wound-healing problems,⁹⁸ likely owing to the sympathomimetic effects of nicotine on the microcirculation and coagulability, as well as the effect of carbon monoxide on the oxygen-hemoglobin curve. Reus and colleagues conducted a study evaluating the effect that smoking and smoking cessation had on free flap complications by comparing two similarly matched groups of head and neck cancer patients who were either smokers who abstained from smoking in the perioperative period or nonsmokers.⁹⁹ Although there was no statistically significant difference between the two groups in terms of flap survival, the smoking group had significantly more recipient-site wound-healing problems than the nonsmoking group. Alcohol dependence is another significant problem that is commonly seen in patients with head and neck cancer, and these patients are often at risk of perioperative alcohol withdrawal or delirium tremens. The astute clinician will identify patients preoperatively who are at risk of nicotine or alcohol withdrawal and take appropriate prophylactic measures.

Malnutrition has been identified as a poor prognostic indicator in cancer-related morbidity and mortality and has been shown to occur in 30 to 50% of patients undergoing head and neck cancer treatment. Preoperative weight loss greater than 10% has been associated with decreased overall survival in head and neck cancer patients.¹⁰⁰ Additionally, negative nitrogen balance impairs wound healing by decreasing tensile strength and increasing the infection rate. Most patients undergoing cancer-related therapies will have their ability to take food orally significantly affected; therefore, liberal placement of gastrostomy tubes to assist in enteral nutrition is highly recommended.

The presence of significant cardiovascular and pulmonary disease has long been recognized as a risk factor for patients undergoing surgery with general anesthesia. A thorough patient history and appropriate diagnostic studies, such as pulmonary function tests, electrocardiograms, and cardiac stress tests, should be obtained when clinically indicated. Diabetes and peripheral vascular disease may make the use of some microvascular free flaps inadvisable owing to donor-site limitations. Patients undergoing fibular transplantation should be examined for signs of vascular insufficiency; however, many authors now argue that, even in the presence of known atherosclerotic disease, there is little benefit for preoperative angiography.^{101–103} Although routine

angiography or magnetic resonance angiography is not an absolute necessity prior to free tissue transfer, judicious use of these diagnostic modalities is encouraged, especially in the face of abnormal pulse examinations or when evidence of peripheral vascular disease is present.

Some studies have found age to be an important predictor of outcome in head and neck reconstruction, whereas others have not found this to be the case. Shestak and Jones reported a 99% free flap viability rate in patients aged 50 to 79 years; however, there was a 45% medical complication rate.¹⁰⁴ They identified patients with an American Society of Anesthesiologists (ASA) class 3 or 4 condition as having a higher risk of morbidity and mortality. Chick and colleagues concurred with these findings and further demonstrated that medical morbidities and wound complications occurred twice as often in patients over age 65 years than in patients younger than 65 years.¹⁰⁵ More recently, Howard and colleagues reviewed their experience with 211 free flaps in 211 patients older than age 70 years.¹⁰⁶ Flap survival and surgical and medical complication rates were 100%, 35%, and 11%, respectively, in patients 70 to 79 years old and 97%, 59%, and 40%, respectively, in patients older than 80 years. Univariate analysis demonstrated that age was associated with medical complications but not surgical complications. Using multivariate analysis, the authors found that alcohol use and coronary artery disease were independent predictors of overall, medical, and surgical complications. It appears that free tissue transfer may be performed in patients over age 70 years with a high degree of technical success but that perioperative morbidity and mortality may increase with age. In our own review of 305 consecutive microvascular free flaps, age was not found to be a significant factor in flap survival or complications, possibly owing to judicious selection of patients whom we subject to major free flap reconstruction.¹⁰⁷

Procedure-Related Considerations

Timing

As stated previously, the goal of mandibular reconstruction is the restoration of form and function by normalizing appearance, mastication, deglutition, speech, and oral competence. The timing and prioritization of these goals within the context of ablative surgery and radiotherapy dedicated to curing the patient of cancer, if possible, have been controversial. Proponents of a delayed or staged approach advocate a period of observation during which the tissue can be monitored for tumor recurrence and the tissue bed may be prepared to receive final bony reconstruction.^{108,109} Advocates of an immediate approach point to the fact that many patients with head and neck malignancies die before

receiving reconstruction and that most patients strongly prefer immediate reconstruction at the time of the ablative surgery.^{86,110} Health-related QOL studies have shown that reconstruction at the time of ablation significantly improves QOL,¹¹¹ that complications negatively affect QOL,¹¹² and that QOL is an important predictor of treatment outcome.¹¹³ Lawson and colleagues reported their experience with mandibular reconstruction in 54 patients with composite mandibular continuity defects who were reconstructed with iliac crest corticocancellous bone grafts with and without titanium mesh cribs combined with various regional pedicled soft tissue flaps.¹¹⁴ Thirty patients underwent delayed reconstruction and 24 patients underwent immediate reconstruction using similar techniques via a transcervical approach. The reported success rate in the delayed group was 90% compared with 46% in the immediate group. Analysis of the patients in whom continuity of the mandible was restored revealed that although most showed a cosmetic improvement, few had significant functional benefits. This dysfunction was attributed to malalignment of the jaws, fibrosis limiting mandibular opening, and failure to provide adequate osseous bulk to undergo prosthetic restoration of occlusion. Most importantly, this study demonstrated that nonvascularized bone grafts should not be used for immediate reconstruction. Subsequently, other studies have demonstrated excellent results with a staged approach to mandibular reconstruction using corticocancellous bone grafts, cribs, and regional flaps.^{58,115} There are, however, strong arguments against delaying definitive reconstruction. With the development of microvascular surgery, vascularized bone transfer has been shown to result in successful restoration of form and function in more than 90% of cases.^{116–126} Additionally, it is associated with reduced cost and length of hospital stay when compared with other traditional modalities, in part because it is performed primarily at the time of ablative surgery.¹²⁷ In the past, proponents of delayed reconstruction pointed to the need to confirm clear bony surgical margins prior to completing reconstructive surgery; however, this has not proven to be a significant clinical problem.¹²⁸ We believe primary reconstruction with vascularized tissue to be the gold standard based on the following: (1) unpredictable results using nonvascularized bone grafts in primary surgery, (2) predictable primary reconstruction provided by vascularized tissue, and (3) strong patient preference toward immediate reconstruction.

Procedures

The choice of technique in oromandibular reconstruction depends partly on the anatomy of the defect. This relies more specifically on the type of defect as it relates to (1) the length of the bony deficiency, (2) the location of the bony deficiency,

Table 50-1 Options in Maxillofacial Reconstruction

Alloplasts
Kirschner wire
Steinmann pin
Polymeric silicone
Acrylic
Titanium/resorbable crib
Titanium reconstruction bar/plate
Nonvascularized tissue transfer
Autogenous
Iliac crest
Tibia
Mandible
Cranium
Combination grafts
Skin grafts
Distraction osteogenesis
Pedicled tissue transfer
Soft tissue flaps
Pectoralis major
Platysma
Temporalis
Buccal fat
Bone flaps
Rib—pectoralis major osteomyocutaneous flap
Free tissue transfer
Fibular osteocutaneous free flap
Radial forearm osteofasciocutaneous or fasciocutaneous free flap
Scapular osteocutaneous free flap
DCIA free flap

(3) the presence of an intraoral mucosal or external skin soft tissue deficiency, and (4) tissue bed vascularity. The reconstructive options for restoring mandibular continuity currently available to clinicians include the use of a reconstruction plate with or without a soft tissue flap, nonvascularized corticocancellous bone grafts with or without a soft tissue flap, composite free tissue transfer, and bifocal or trifocal distraction osteogenesis (Table 50-1).

No Reconstruction

The first option in mandibular reconstruction is also the simplest: no reconstruction. Although rarely performed today, collapse of the mandibular segments is occasionally acceptable for patients with advanced malignant tumors and defects of the ascending ramus and lateral body. This results in deviation of the chin to the affected side and elevation of the tongue on the affected side (Figure 50-2). The advantage is that it shortens the operation and can speed recovery in elderly patients with very poor prognoses. The disadvantage is that speech and swallowing may be adversely affected depending on the amount of soft tissue resected.



FIGURE 50-2 Patient with an unreconstructed continuity defect of the right lateral mandible. A, Deviation of the chin to the affected side; B, elevation of the tongue to the affected side.

Alloplastic Reconstruction: Reconstruction Plates

The second option is also simple: plate reconstruction. Large reconstruction plates are useful for spanning continuity gaps of the mandible and have the following advantages: they are easily adaptable, they can restore jaw function, and they allow stabilization of the bony segments for secondary reconstruction if so desired (Figure 50-3). The disadvantages are that they

rely on soft tissue coverage, bulk, and vascularity; they do not restore functional occlusion; they have an extremely high failure rate for anterior defects; they are unesthetic in the anterior mandible and angle; and they will ultimately fatigue and fracture. They are indicated for use in patients with defects of the lateral or ascending ramus, elderly patients with a poor prognosis, or those patients with benign tumors undergoing a staged reconstruction. Complications are

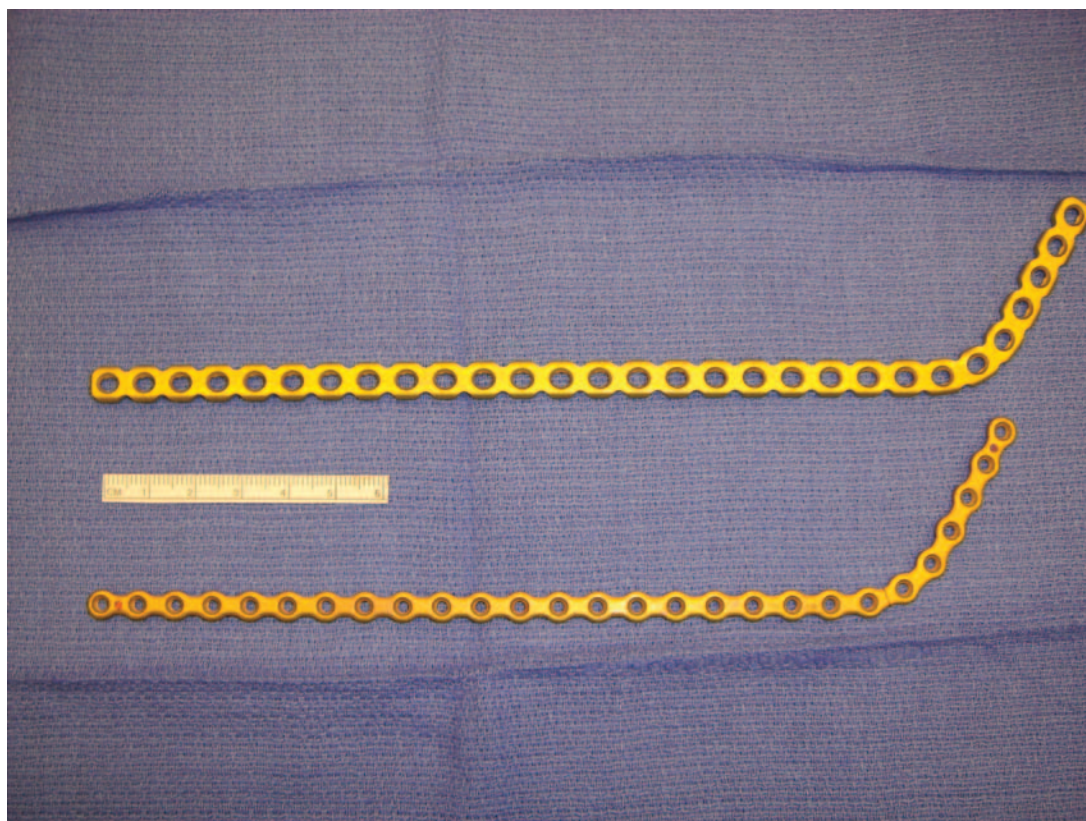


FIGURE 50-3 Locking reconstruction plates, 2.4 mm and 2.0 mm.

frequent and include plate exposure, screw to bone failure, and plate fracture (Figures 50-4 and 50-5). Reconstruction plates are destined to fail if placed in the anterior mandible, into poorly vascularized tissue, or into a patient with an exceptionally strong bite force. Patients requiring plate-only reconstruction with inadequate tissue and who are at risk of plate exposure should be reconstructed with a local or regional soft tissue flap. The options for plate coverage include the pectoralis major myocutaneous flap, platysma flap, nasolabial flap, and radial forearm free flap.

Multiple studies have evaluated the use of reconstruction plates, with and without soft tissue flaps, and have found them to be effective in bridging gaps for a finite period of time. Unfortunately, they are universally doomed to failure and are associated with complication rates between 30 and 100%.¹²⁹⁻¹³⁹ These studies are limited by virtue of their retrospective nature, a highly selected patient population (generally elderly patients with poor performance status), and inadequate follow-up. Early plates made of steel or Vitallium were characterized as being bulky or awkward and were associated with a high rate of complications. The Titanium Hollow Screw Osseointegrating Reconstruction Plate (THORP) system was introduced in the 1980s and was found to be superior to solid screw steel plates in terms of plate extrusion and exposure.¹⁴⁰ More recently, locking titanium reconstruction plates in varying sizes (2.0, 2.4, and 2.7 mm) were commercially introduced that have largely replaced the older THORP system. Adequate stability of the proximal and distal bony segments is important for favorable outcome, regardless of the plate size. Haug found that three bicortical screws placed into each segment provided maximum resistance to deformation,¹⁴¹ and Freitag and colleagues found fewer complications when four screws were placed into each segment.¹⁴² For these reasons, we recommend a minimum of four screws on each segment when possible to assist in stabilization and load-bearing potential.

Although reconstruction plates may be used for isolated lateral mandibular defects, their use for continuity defects of the anterior mandible has been problematic. Several studies have documented high complication rates related to plate exposure in the chin region.^{129,134,137,139} The mechanisms of intraoral and extraoral plate exposure have been attributed to stripping of the muscular attachments, denervation of the lower lip musculature, ptosis of the lower lip, and pressure necrosis. Boyd and colleagues showed that extensive mandibulectomy defects involving the anterior arch will fail in up to 87% of the cases.¹³⁷ Kim and Donoff had similar findings; they concluded that there was a high complication rate with plates alone and

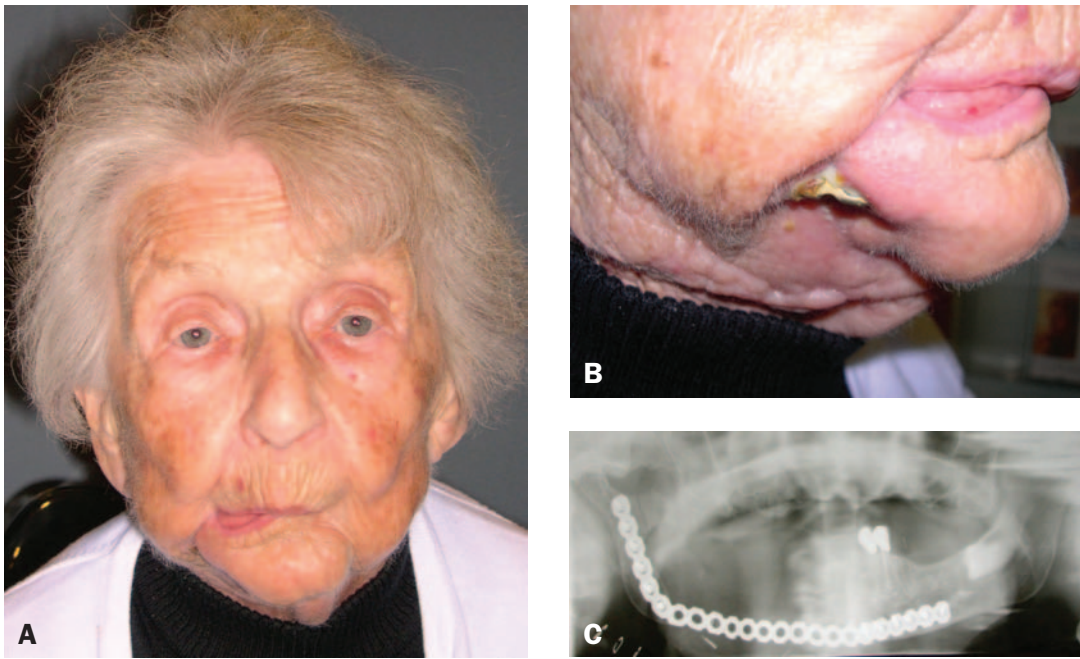


FIGURE 50-4 Elderly patient who underwent composite resection of the floor of the mouth and mandible for advanced-stage squamous cell carcinoma and was reconstructed with a 2.4 mm bridging plate alone. Note the exposed plate owing to a lack of adequate soft tissue bulk and unfavorable tongue position and mobility, resulting in oral incompetence. A, Frontal view; B, close-up of exposed plate; C, panoramic radiograph.

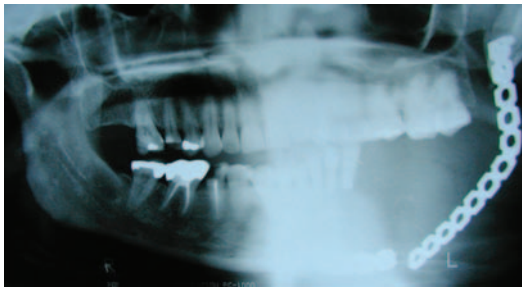


FIGURE 50-5 Panorex radiograph of a patient with a continuity defect of the lateral mandible treated with a reconstruction plate alone. Excessive masticatory forces resulted in primary failure of the hardware and plate fracture.

recommended soft tissue coverage to reduce the rate of plate exposure.¹⁴⁴ In general, however, the use of soft tissue flaps does not appear to prevent plate exposure, particularly in the anterior arch, and once it occurs, recoverage is unpredictable. Free flaps have been shown to perform better than pedicled flaps for this purpose. Schusterman and colleagues noted only a 33% success rate with plates placed into the anterior arch compared with a 93% success rate when placed into lateral defects.¹⁴³ Overall, 25% of their plates became exposed, and of these, four of five of them occurred in the anterior arch.

Even with plate coverage, success rates without bony reconstruction remain poor. Wei and colleagues recently reviewed a series of 80 patients

who underwent reconstruction of composite mandibular defects using titanium reconstruction plates combined with soft tissue free flaps.¹⁴⁵ The overall complication rate was 69.2%. Plate exposure was the most common complication, occurring in 46% of the patients. Other complications included soft tissue deficiency and mandibular contour deformation, intraoral contracture and a lack of gingivobuccal sulcus, oral incontinence, trismus, and tongue adhesion. Of those patients with complications, 78% underwent a second salvage procedure, including reconstruction with a fibular osteoseptocutaneous flap ($n = 20$), removal of the exposed reconstruction plate ($n = 9$), revision with local or pedicled soft tissue flaps ($n = 4$), or skin grafts ($n = 2$).

Radiation therapy has been thought to contribute to the complications related to plate reconstruction, either alone or combined with soft tissue flaps. Ryu and colleagues demonstrated significant plate loss when patients were irradiated shortly following surgery but did not have significant plate loss when the patients received radiation beyond 10 months of surgery.¹⁴⁶ Raveh and colleagues found that plate loss in patients with benign disease is less frequent.¹⁴⁷ Furthermore, Yi and colleagues observed significant differences between the rates of success in irradiated (76% complications) and nonirradiated patients (15.4% complications).¹⁴⁸ Generally, we reserve the use of plate reconstruction, alone or in combination with soft tissue flaps, to patients with isolated lateral defects, poor prognoses, and no planned radiation.

Autogenous Reconstruction

Successful reconstruction of tissue defects resulting from trauma or tumor resection is dependent on the survival of the transplanted tissue, which, in turn, is dependent on an adequate blood supply or soft tissue envelope. Attempted bony reconstruction of the jaws without addressing the integrity of the soft tissues is condemned to failure. The grafted tissues are characterized by variable degrees of vascularity and tissue-specific demands for oxygen and can be classified based on their blood supply: (1) nonvascularized, (2) pedicled, and (3) vascularized.

Nonvascularized Bone Grafts Nonvascularized tissue transfer implies the complete and permanent separation of tissue from its blood supply. Survival of the graft occurs by diffusion and gradual vascular ingrowth from the recipient site. Revascularization occurs by well-known mechanisms involving the ingrowth of capillaries at the rate of 0.3 to 0.4 mm/d and is commonly preceded by graft resorption.¹⁴⁹ Much has been learned about the biology of bone repair since Axhausen's rudimentary description of bone healing.¹⁵⁰ In what is now known as the "osteoblastic theory," he theorized that bone marrow and periosteum survive transplantation and produce bone. Phemister later observed that the production of bone was related partly to necrosis of host bone and partly to the induction of new bone from transplanted tissue, a process he termed "creeping substitution."¹⁵¹ This biphasic cellular proliferation and resorption process was further defined by Urist, Urist and Strates, and (another) Axhausen in the mid-1950s.^{152,153} Urist later identified a family of regulated osteoinductive proteins known as bone morphogenetic protein.^{154,155} We now know that bone morphogenetic protein causes the differentiation of stem cells into osteoblasts via a transmembrane receptor complex response, the genetic mechanisms of which continue to be elucidated and are beyond the scope of this chapter.¹⁵⁶⁻¹⁶⁴ The requirements for successful vascular ingrowth are secure immobilization and intimate contact of a tissue with an abundant intercellular matrix. Although various donor-site options are available to the surgeon, including the rib, tibia, calvarium, and mandible, the iliac crest has traditionally supplied the most predictable quantity and quality of bone suitable to reconstruct segmental mandibular defects.

The ilium has evolved into the most versatile and commonly used source of corticocancellous bone grafts.¹⁶⁵⁻¹⁷⁵ It enjoys the advantages of providing a large volume of bone (up to 50 cc in the anterior ilium and 90 cc in the posterior ilium) that is easily obtained, and it can be harvested simultaneously with other maxillofacial procedures. The graft may be obtained as a "block" of corticocancellous bone, or, alternatively, large

volumes of cancellous marrow can be harvested by either an anterolateral, an anteromedial, or a posterior approach. Previously, many surgeons preferred the former method, based on the Manchester principle, which required an anterolateral approach and resulted in considerable donor-site morbidity in terms of pain and gait disturbance.⁴⁸ Studies investigating postoperative morbidity associated with the different harvesting techniques are severely limited by virtue of variations in technique and patient selection. Nevertheless, Marx and Morales showed that a posterior approach will result in less postoperative gait disturbance and yield a greater volume of bone when compared with the anterolateral approach.¹⁷⁶ Owing to the widespread acceptance of cancellous cellular bone grafting, anterolateral approaches for block grafts have become largely unnecessary. The primary disadvantage with the posterior approach is that prone positioning makes simultaneous harvest impossible and operating room times are increased. We prefer an anteromedial approach for harvesting moderate and large volumes of corticocancellous bone. By restricting muscle stripping to the medial aspect of the ilium (the iliacus muscle), pain and gait disturbance are considerably less than those seen with the anterolateral approach, and the operation can be performed using a “two-team” approach. Although unilateral harvest is occasionally insufficient for large continuity defects of the mandible and a posterior approach is occasionally needed for severe osteoporotic patients, we will not hesitate to harvest bone from both sides of the ilium. Patients tolerate the procedure well, and complications are uncommon (generally less than 5% in experienced hands), including hematoma, seroma, neurosensory changes, gait disturbance, fractures of the iliac wing, peritoneal perforation, infection, and sacroiliac instability.

Technique for Iliac Crest Bone Graft Harvest

• Anterior

The anatomic landmarks for harvest from the anterior ilium are the anterior superior iliac spine and crest, as well as knowledge of the location of various sensory nerves in the region (Figure 50-6A). The nerve branches most at risk are the lateral cutaneous branch of the subcostal nerve (T12) and the lateral cutaneous branch of the iliohypogastric nerve (L1). The lateral femoral cutaneous nerve is located anterior and medial to the anterosuperior iliac tubercle. The patient is placed in the supine position, and a hip roll is placed on the harvest side. The skin overlying the iliac crest is retracted superiorly to allow the incision to rest 1 to 2 cm below the iliac crest and approximately 1 to 2 cm posterior to the anterosuperior iliac tubercle. The incision is made through skin and subcutaneous tissue, and

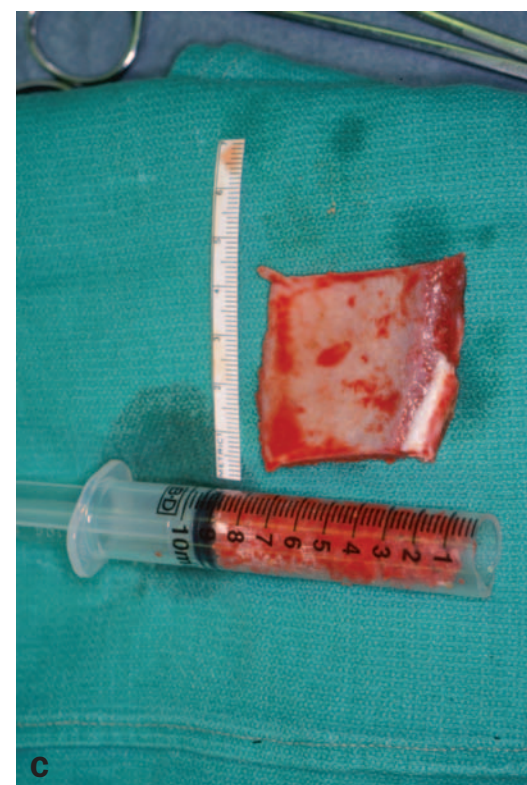
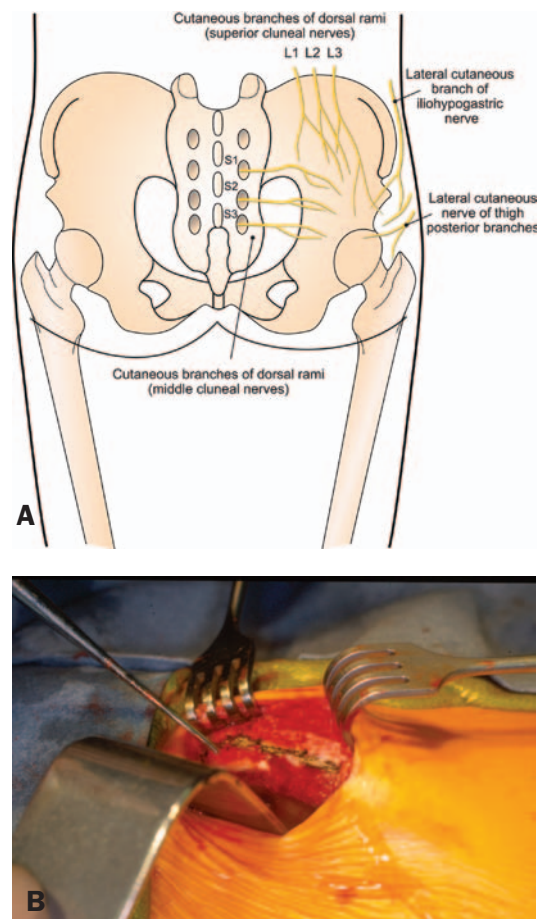


FIGURE 50-6 Anterior iliac crest bone graft harvest. A, Regional anatomy; B, approach; C, cortical block and cancellous bone graft. A reproduced with permission from Marx RE.²⁰⁰

dissection proceeds down to the fascia overlying the tensor fascia lata and external oblique muscles. Sharp dissection is continued between these muscle insertions along the crest of the bone through the periosteum. Careful subperiosteal dissection then proceeds medially, laterally, or both depending on the clinical situation. Whenever possible, the anteromedial approach is preferred. Lateral dissection and reflection of the tensor fascia lata and external obliques result in substantially increased pain and prolonged gait disturbance. Following medial dissection to reflect the iliacus muscle in a subperiosteal plane, a Taylor retractor is placed to facilitate medial retraction of the iliacus muscle and protect the peritoneal contents (Figure 50-6B). Large quantities of cortical or corticocancellous bone can then be harvested using a combination of a reciprocating saw, straight and curved osteotomes, and bone curets (Figure 50-6C). A hemostatic dressing is placed into the wound following bone harvest (Gelfoam), and the wound is closed in layers. Suction drains are generally not necessary.

• Posterior

Harvest from the posterior iliac crest is another popular approach for obtaining large-volume bone grafts. The patient is placed in the prone

position with a moderate amount of flexion and placement of a hip roll (Figure 50-7A). The important landmarks are the spinous processes of the vertebra and the posterosuperior iliac crest and spine (Figure 50-7B). Relevant nerves include the superior and middle cluneal nerves, L1 to S3 (Figure 50-7C). A curvilinear incision is made through the skin overlying the iliac crest. A bovie is then used to dissect down through the fibroadipose tissue, and the posterosuperior crest is identified. The fascia overlying the abdominal and gluteal muscles is divided, and an incision is made through the periosteum. Subperiosteal dissection then proceeds by retracting the tissue laterally and taking care to avoid the sacroiliac ligament. Bone is harvested in a fashion similar to that of the anterior approach.

Technique for Inset of Corticocancellous Bone Graft and Biodegradable Crib

Reconstruction is performed with a two-team approach. As one team harvests the iliac crest bone graft, the second team prepares the recipient bed for grafting. The mandible is approached via an extraoral incision placed within a prominent skin crease at least 3 to 4 cm beneath the inferior border of the mandible. The incision is carried through skin, subcutaneous tissue, and platysma. Superior and inferior skin flaps are

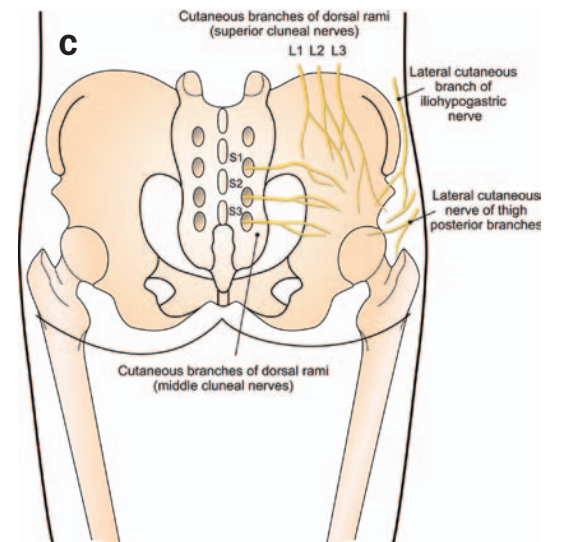
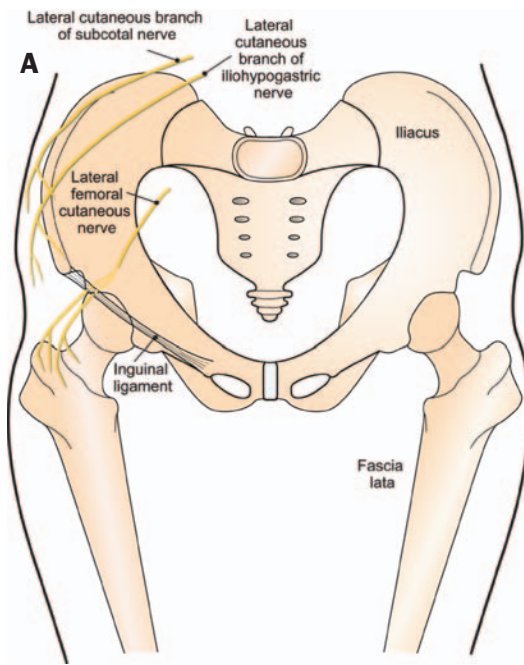


FIGURE 50-7 Posterior iliac crest bone graft harvest. A, Prone positioning; B, regional anatomy; C, approach; D, corticocancellous bone graft. A and B reproduced with permission from Marx RE.²⁰⁰

developed in a subplatysmal plane and stapled to the adjacent skin. The superficial layer of the deep cervical fascia is horizontally incised, and a fascial flap containing the marginal mandibular branch of the facial nerve is mobilized superiorly off the submandibular gland (Figure 50-8B). The posterior facial vein may be identified, ligated, and divided if encountered. The inferior border of the native mandible is identified and incised on the proximal and distal bony segments, which are then skeletonized in a subperiosteal plane. A tunnel is created between the proximal and distal bony segments with care taken to preserve the integrity of the oral mucosa. With the patient placed into stable intermaxillary fixation, a reconstruction plate is adapted to the proximal and distal segments and stabilized with four locking screws on either side of the defect (Figures 50-8C and D). A biodegradable mesh plate is then heated

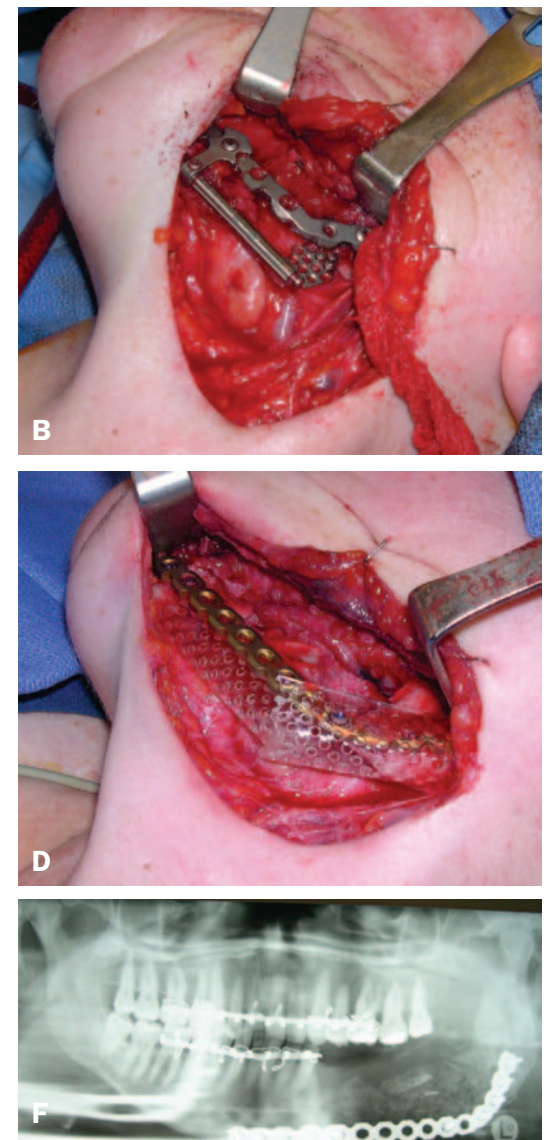
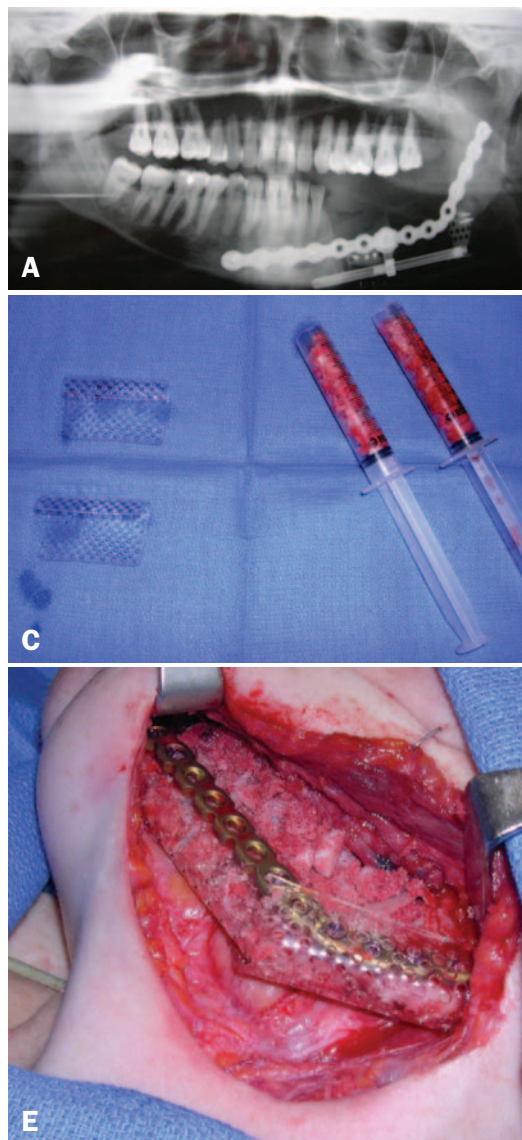


FIGURE 50-8 Technique for iliac crest corticocancellous grafting for segmental defects of the mandible using a biodegradable crib. A, Panoramic radiograph of a patient with a segmental mandibular defect following resection of an ameloblastoma and failed attempt at reconstruction using transport distraction osteogenesis; B, approach; C, biodegradable cribs and corticocancellous bone graft; D, application of a 2.4 mm locking reconstruction plate and adaptation of a biodegradable crib; E, placement of a corticocancellous bone graft; F, immediate postoperative panoramic radiograph.

and adapted and secured to the plate and surrounding bony segments to act as a crib for the bone graft (see Figure 50-8D). Approximately 25 to 30 cc packed corticocancellous bone is placed into the defect (Figure 50-8E). A layered primary closure is performed over a suction drain.

Treatment Outcome: Nonvascularized Iliac Crest

Published success rates for mandibular bone graft reconstruction range from 38 to 100% (Figure 50-9).^{14,35,37,43,48,51,52,58,114,115,177-189} Complications leading to revision or removal of the graft range from 20 to 81%.^{14,35,37,43,48,51,52,58,114,115,177-189} All of these studies are retrospective, observational studies with highly censored cohorts, limited by differences in patient selection, treatment methods, data analysis, and follow-up. In general, patients with short continuity defects and benign disease or post-traumatic deformities have the most predictable outcomes. Important factors that have been found to affect graft survival include the length of the mandibular defect, timing of the reconstruction (immediate versus delayed), pre- or postoperative radiation therapy, postoperative recipient-site complications, malignant diagnosis, intraoral communication, estimated blood loss, the number of days on postoperative antibiotics, and the use of soft tissue flaps (Table 50-2).¹⁸⁸

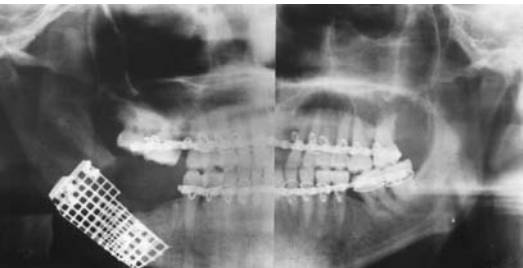


FIGURE 50-9 Failed nonvascularized bone graft used to reconstruct a segmental mandibular defect. Note the titanium crib with complete resorption of the bone graft.

Table 50-2 Factors Affecting Bone Graft Survival
Timing
Length of defect
Radiation
Post operative complications
Malignant diagnosis
Intraoral communication
Estimated blood loss
Number of days on antibiotics
Use of soft tissue flaps
Reproduced with permission from August M, Tompach P, Chang YC, Kaban LB. Factors influencing the long-term outcome of mandibular reconstruction. J Oral Maxillofac Surg. 2000;58:731.

The length of the mandibular defect has been shown to be an important factor in bone graft survival. Foster and colleagues critically evaluated the use of nonvascularized grafts compared with microvascular composite free flaps in reconstruction of mandibular continuity defects and found that success was dependent in part on the length of the defect.¹⁸⁶ Success rates in terms of an osseous union using nonvascularized bone grafts decreased significantly in those patients with defects greater than 6 cm. The overall success rate of nonvascularized bone grafts was approximately 69%, whereas the overall success rate of vascularized bone flaps was 96%. Additionally, it took an average of 2.3 operations to complete the reconstruction for those patients with nonvascularized bone grafts as opposed to only 1.1 operations for those patients with vascularized bone flaps. A follow-up study at the same institution by Pogrel and colleagues reported an increased rate of failure for continuity defects greater than 9 cm and recommended that vascularized grafts be used in such cases to improve outcome.¹⁸⁷ These findings were further supported in a more recent study by August and colleagues, who reviewed a series of 70 cases of mandibular reconstruction performed at their institution over a 15-year period in an attempt to identify factors that affect the long-term outcome.¹⁸⁸ All except two patients underwent reconstruction using corticocancellous bone grafts, occasionally combined with a sternocleidomastoid flap. Overall success, defined as wound closure, freedom from infection, bony continuity, and maintenance of bulk, was remarkably similar to that of Foster and colleagues,¹⁸⁶ at 68.8%. The failure rate was highest in defects with an average length of 9.9 cm, whereas the average length of successfully reconstructed defects was 7 cm. For these reasons, we recommend vascularized free flaps when planning the reconstruction for patients with continuity defects of the mandible greater than 6 to 9 cm. Nonvascularized bone grafts, generally harvested from the iliac crest, are reserved for delayed reconstruction of segmental defects less than 6 cm, in whom no radiation is planned and in whom there is adequate soft tissue. The exception is in the pediatric population in whom nonvascularized bone grafts appear to be much more predictable.¹⁸⁹ Corticocancellous bone may be placed into a resorbable crib along with a reconstruction bar for added stability and precision.

The tissue of patients who have undergone radiation therapy is hypocellular, hypovascular, and hypoxic.¹⁹⁰ Morbidity associated with radiation therapy is considerable and includes poor wound healing, xerostomia, hair loss, mucositis, radiation caries, trismus, and osteoradionecrosis (ORN). The preponderance of evidence suggests that radiation therapy significantly affects outcome with regard to bone graft reconstruction of the mandible.^{14,35,37,43,48,51,52,58,114,115,177-189} Although

some studies have failed to identify a definite association between radiation therapy and bone graft survival,^{57,58,114,115,188,191} many studies have demonstrated worse outcome and a significantly higher complication rate when reconstructing therapeutically irradiated tissues.^{44,179,180-185,192} Conventional mandibular reconstruction using nonvascularized bone grafts in irradiated patients has resulted in success rates between 20 and 91% and complications as high as 81% (see Figure 50-10).^{44,57,58,114,115,179-185,191,192} In an effort to improve success rates, surgeons began to use various pedicled myocutaneous and osteomyocutaneous flaps to prepare a vascularized recipient bed.^{56,67,182,192-197} Marx and colleagues popularized the use of HBO as an adjunct to soft tissue flaps in managing irradiated tissue.^{57,58,109,190,198-201} In a classic study reviewing the secondary reconstructions of 17 patients with composite mandibular defects, Marx and Ames used HBO to enhance osteogenesis and improve soft tissue wound healing.⁵⁸ The protocol consisted of 20 HBO treatments preoperatively (100% oxygen at 2.5 atm for 90 minutes) followed by 10 treatments postoperatively. Using autogenous particulate bone and marrow within a custom-made stainless steel mesh crib or freeze-dried allogeneic bony crib, they reported a 91.6% success rate in the 12 patients within the group who had previously received radiation.

Recently, platelet-rich plasma (PRP) has been advocated as an adjunct to improve cancellous cellular bone grafting.²⁰² The use of autologous PRP is thought to enhance the initial angiogenic response of the recipient site, acts as a useful carrier medium, and may result in more efficient graft maturation.²⁰³⁻²⁰⁶ The data related to bone graft healing have been conflicting in both experimental and clinical studies. It is possible that PRP enhances early autologous graft healing, but this effect does not seem to be significant for more than 2 months.²⁰⁷ Furthermore, other investigators have failed to find any benefit to adding PRP to autogenous bone in a number of clinical situations.^{208, 209} Although enthusiasm for PRP has been great, the true efficacy of this adjunctive substance awaits further elucidation.

Complications are frequently encountered in mandibular reconstruction and may result in bone graft failure. Complications implicated in poor outcome include infection, wound dehiscence, oral contamination, graft resorption, non-union, cardiovascular complications, and tumor recurrence. Of these, inadvertent perforation of mucosa and skin and resultant oral contamination have been particularly worrisome. Carlson and Monteleone recently reviewed a series of 211 consecutive patients who underwent cancellous cellular bone grafts for segmental mandibular defects, 5.2% of whom experienced inadvertent perforation of the skin and/or mucosa.¹¹⁵ Analysis

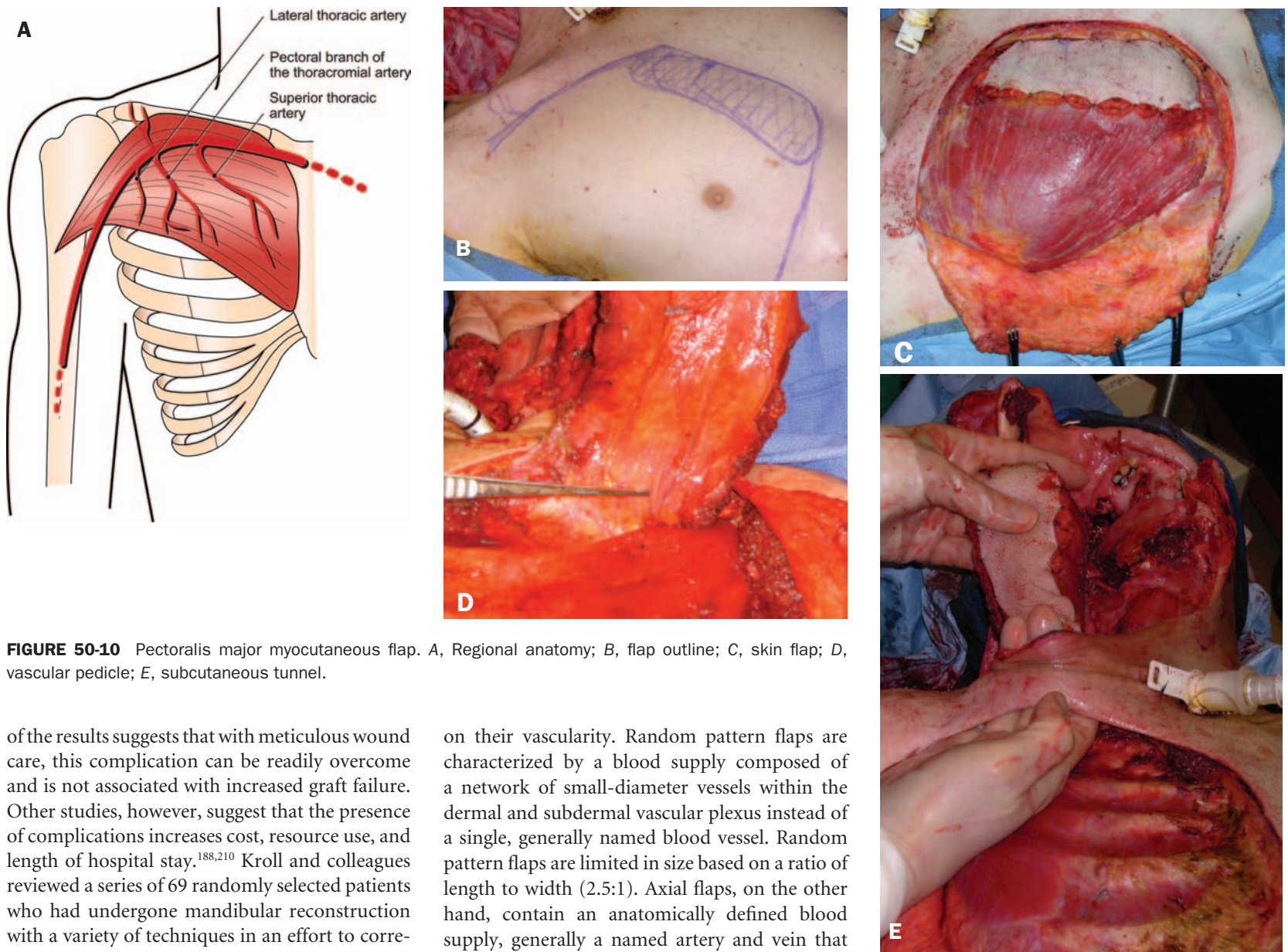


FIGURE 50-10 Pectoralis major myocutaneous flap. A, Regional anatomy; B, flap outline; C, skin flap; D, vascular pedicle; E, subcutaneous tunnel.

of the results suggests that with meticulous wound care, this complication can be readily overcome and is not associated with increased graft failure. Other studies, however, suggest that the presence of complications increases cost, resource use, and length of hospital stay.^{188,210} Kroll and colleagues reviewed a series of 69 randomly selected patients who had undergone mandibular reconstruction with a variety of techniques in an effort to correlate differences in cost and complications between the different procedures.²¹⁰ The results showed that immediate reconstruction was more cost-effective than delayed reconstruction and that the incidence of complications was significantly higher in the nonvascularized techniques than in microvascular free tissue transfer.

Pedicle Tissue Transfer Pedicle tissue transfer implies maintaining the vascular supply to the grafted tissue through either random pattern or axial pattern vasculature. The size of the defect and the local or regional vascular anatomy influence the type of flap, which may consist of skin, fascia, muscle, bone, or multiple tissue types. Each of these flaps is dependent on a complex system of macrocirculation and microcirculation. The amount of tissue that can be safely transferred is dependent on classification of the flap, that is, random versus axial pattern, dominant pedicle (type I) versus segmental pedicle (type IV).

Pedicle skin flaps have been classified as random pattern flaps or axial pattern flaps based

on their vascularity. Random pattern flaps are characterized by a blood supply composed of a network of small-diameter vessels within the dermal and subdermal vascular plexus instead of a single, generally named blood vessel. Random pattern flaps are limited in size based on a ratio of length to width (2.5:1). Axial flaps, on the other hand, contain an anatomically defined blood supply, generally a named artery and vein that travels within the flap. Axial pattern flaps therefore are not limited in dimension like their random pattern counterparts.

Pedicle muscle flaps and myocutaneous flaps continue to be widely used in head and neck reconstruction. The characteristics of the pedicle (location, length) and whether a given muscle is expendable determine which muscle flaps are best suited for transfer. Mathes and Nahai established a classification system of muscles based on the number of dominant vascular pedicles nourishing each muscle: type I, one single supplying vessel; type II, one dominant and one minor pedicle; type III, two dominant pedicles; type IV, segmental pedicles; and type V, one dominant pedicle with secondary segmental pedicles.²¹¹

Pectoralis Major Myocutaneous Flap

Originally described by Pickeral and colleagues as a turnover flap for chest wall reconstruction in 1947,²¹² the pectoralis major myocutaneous

flap was not widely used in head and neck reconstruction until relatively recently. During the 1980s, Ariyan and Ariyan and Cuono popularized the use of the “pec major” flap for reconstruction of head and neck defects.^{56,213} Its ease of harvest, reliability, bulk, and proximity made it the “workhorse flap” for the reconstruction of oral and oropharyngeal defects. The flap is based on the thoracoacromial artery, which, in turn, originates from the second portion of the axillary artery (Figure 50-10).²¹⁴ The medial portion of the muscle and overlying skin are supplied by the internal mammary perforators, which anastomose with the thoracoacromial artery branches. The medial aspect of the muscle is the most reliable area on which to design a skin paddle that can supply up to 400 cm² of skin transfer. The flap can also be used without a skin paddle, and the exposed muscle will mucosalize in the oral and oropharyngeal environment, or a skin graft

can be applied for external coverage. The advantages are that it provides a generous skin paddle overlying robust muscle with a consistent blood supply. The disadvantages are that it is often too bulky for the oral cavity, it has a tendency to separate from the point of inset owing to the pull of gravity, and there is distortion of symmetry and function at the donor site.

Pedicated bone flaps, or myocutaneous composite flaps, have been advocated for reconstruction of composite tissue defects in the head and neck.^{56,67,182,192–197} By maintaining the musculoperiosteal blood supply, transposing bone attached to muscle can be a viable alternative to nonvascularized bone grafts. Unfortunately, the blood supply to the periosteum is not only dependent on the musculoperiosteal system. There are also fascioperiosteal contributions and important medullary contributions to bony segments. Since substantial portions of the blood supply to bone are dependent on the medullary vascular system and the periosteal blood supply is inconsistent, the viability of the transferred bone segment, in flaps such as the pectoralis major or temporalis, is unpredictable.

Technique for Pectoralis Major Myocutaneous Flap Harvest

The clavicle and lateral border of the sternum are outlined and skin paddles (if necessary) are marked on the inferomedial portion of the flap, corresponding to the size of the defect (see Figure 50-10B). A curving C-shaped incision is made to encompass the skin paddle and allow the breast and skin to be elevated off the chest wall. Skin and subcutaneous tissues are incised down to the pectoralis fascia, encircling the skin paddle. The inferolateral extent of the pectoralis major muscle is identified, and the plane between the pectoralis major and minor is entered (see Figure 50-10C). Some authors advocate suturing the skin paddles to the underlying muscle to prevent cleavage while inseting the flap. The pectoralis major is then elevated off the chest wall as its origins on the ribs are divided by sharp dissection (see Figure 50-10D). The plane between the pectoralis major and the intercostal muscles must be preserved to prevent inadvertent entry into the chest. Medial dissection is now performed on the lateral aspect of the sternum, maintaining a submuscular plane of dissection to the clavicle. Internal mammary perforators, particularly to the second and fourth intercostal space, must be identified and ligated to prevent troublesome bleeding. As the pectoralis flap is advanced cephalad, the lateral thoracic artery is divided and ligated to optimize the arc of rotation. The vascular pedicle is located on the upper lateral portion of the flap, and the pectoral branch of the thoracoacromial artery is visualized on the deep surface of the pectoralis major and medial to the pectoralis minor (see Figure

50-10D). The muscle is divided laterally as it courses toward its insertion in the bicipital groove of the humerus to allow a greater arc of rotation and to avoid flap contraction with subsequent arm movement. Once the flap is elevated, a broad subcutaneous tunnel large enough to fit four fingers is created to allow the passage of the pectoralis flap into the neck and chin (see Figure 50-10E). The donor site is closed over a suction drain.

Treatment Outcome: Pectoralis Major Myocutaneous Flap

The pectoralis major myocutaneous flap is noted for its reliability and low incidence of complete flap failure, reported to be between 1 and 7% (Figure 50-11).^{197,215–217} Partial flap necrosis, however, usually manifested as necrosis of the skin paddle, has been reported to be much higher, between 14 and 40%.^{197,215–217} Difficulties have been attributed to pedicle compression (usually through the tunnel to the neck), skin paddle design, and gravitational pull.

Microvascular Free Tissue Transfer As the use of pedicled flaps evolved, and reliable dominant vascular pedicles to bones, muscles, and/or skin regions were identified, surgeons began to divide the vascular pedicle and subsequently perform a vascular anastomosis at the recipient site to avoid the limitations related to pedicled tissue transfer.^{60,61} Fasciocutaneous and musculocutaneous vascular territories were identified for a number of bone segments, which could now be

harvested and used for vascularized tissue transfer, including the fibula, scapula, iliac crest, and second metatarsal bone. Thus, microvascular free tissue transfer was born. With the development of improved instrumentation and the further refinement of microvascular techniques, so-called “free flaps” have largely replaced pedicled flaps for head and neck reconstruction and are now widely used for a variety of reconstructive challenges, including the restoration of mandibular continuity and function. The primary advantages of microvascular free tissue transfer are as follows: (1) the predictability with which the surgeon can bring soft, hard, or composite flaps into a defect regardless of the soft tissue vascularity of the recipient site; (2) it allows immediate reconstruction at the time of ablative surgery; and (3) the donor-site morbidity is relatively minimal. The disadvantages are related to (1) the length of time required for flap harvest and vascular anastomosis and (2) the requirement for additional instrumentation and training. Disa and colleagues popularized a practical approach to oromandibular reconstruction that uses either the fibular osteocutaneous flap or the RFFF for the vast majority of head and neck cases.²¹⁸ For this reason, these two flaps are highlighted in this chapter.

Radial Forearm Fasciocutaneous Free Flap

The RFFF was first described in the Chinese literature by Yang and colleagues in 1981.⁶⁷ Muhlbauer and colleagues then brought it to Europe,⁶⁹ and Soutar and colleagues subsequently popularized

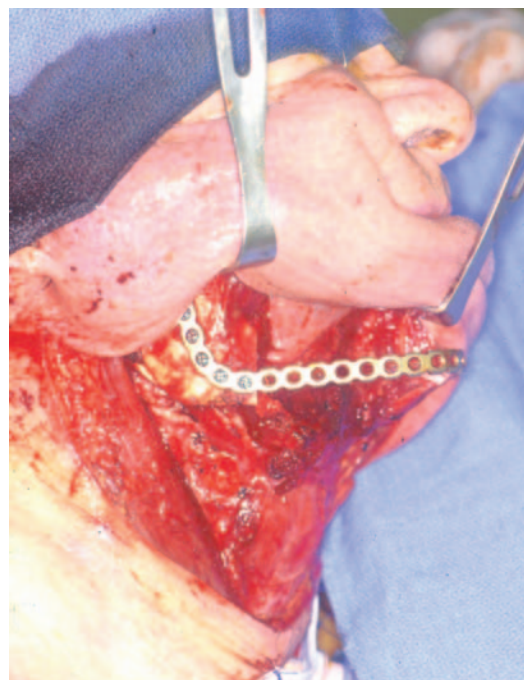


FIGURE 50-11 Composite mandibular defect reconstructed with a 2.4 mm locking reconstruction plate and a pectoralis major myocutaneous flap. A, Intraoperative view; B, postoperative appearance. Note the bulkiness of the flap, which will atrophy over time.

this flap in the United States for use in intraoral reconstruction.⁷⁰ It has since become the most commonly performed flap for a variety of head and neck defects. The RFFF is based off the radial artery and receives venous drainage by way of the deep (venae comitans) and superficial (cephalic vein) venous systems (Figure 50-12).²¹⁹ Sensory nerve supply to the forearm skin is via one of the antebrachial cutaneous nerves, and the flap may be developed as a fasciocutaneous or an osteo-musculofasciocutaneous flap. The RFFF offers a thin pliable skin paddle with a long vascular

pedicle that can be anastomosed to either side of the neck. The skin paddle may include the entire volar skin of the forearm, extending from the antecubital fossa to the flexor crease of the wrist. As a soft tissue-only flap, it has been shown to be highly reliable, with a survival rate greater than 97% and excellent functional outcomes.^{220–224} Complications occur in 14 to 35% of cases and are most commonly related to the donor site.^{224–227} Complete or partial failure of the split-thickness skin graft at the donor site is the most common complication, which can lead to flexor tendon

exposure and delayed wound healing. Technical innovations, such as the use of vacuum-assisted wound care, local muscle flaps, preoperative tissue expansion leading to primary closure, and suprafascial dissection, have been helpful in preventing this complication.^{228–234} Use of the RFFF as a bone-containing flap for composite tissue reconstruction has been more problematic. The radius is a relatively thin bone. Initially, when surgeons harvested the flap as an osteocutaneous flap, little attention was paid toward stabilizing the donor site. Because of this, the radius has been associated with pathologic fracture in 15 to 20% of cases.^{235–237} Restricting the diameter of bone to 40% of the native radius and prophylactic plating have been advocated to reduce the risk of pathologic fracture. Recently, there has been a renaissance in the use of the osteocutaneous RFFF in mandibular reconstruction. Several authors have reported excellent results in the reconstruction of non-tooth-bearing areas of the mandible (posterior body, ramus, condyle), with very little donor-site morbidity.^{238–241} By rigidly fixating the donor radius and placing the patient in a volar splint for 7 days, Villaret and Futran reported no cases of radius fracture in a series of 34 consecutive cases.²³⁸ Although the bone height is marginal, it has been shown to be adequate for successful implant-supported prosthetic rehabilitation. Militsakh and colleagues recently compared the osteocutaneous RFFF with other bone-containing free flaps in mandibular reconstruction.²³⁹ Their results demonstrated comparable donor-site morbidity; however, the RFFF was associated with fewer intensive care unit days (4 vs 7 days), fewer hospital days (13 vs 15 days), and a statistically significant cost savings. They also found function outcomes, such as speech, swallowing, and dental rehabilitation, to be similar between the various techniques.

The RFFF is indicated for the reconstruction of facial, oral, and pharyngeal soft tissue defects and may be used in mandibular reconstruction with some degree of caution. Its advantage lies in its predictability, ease of harvest (45 minutes in experienced hands), and relatively few major complications. The disadvantage is primarily related to donor-site morbidity—owing to tendon exposure, poor esthetics, and radius fracture—and can be limited by local flaps and plating the radius. It is contraindicated in patients with arteriovenous shunts in the forearm and those with inadequate ulnar artery perfusion and relatively contraindicated in patients who have undergone surgery of the ipsilateral hand or those with end-stage renal disease. Allen's tests must be performed preoperatively to document collateral circulation to the radial digits. At our institution, it is the most commonly performed free flap

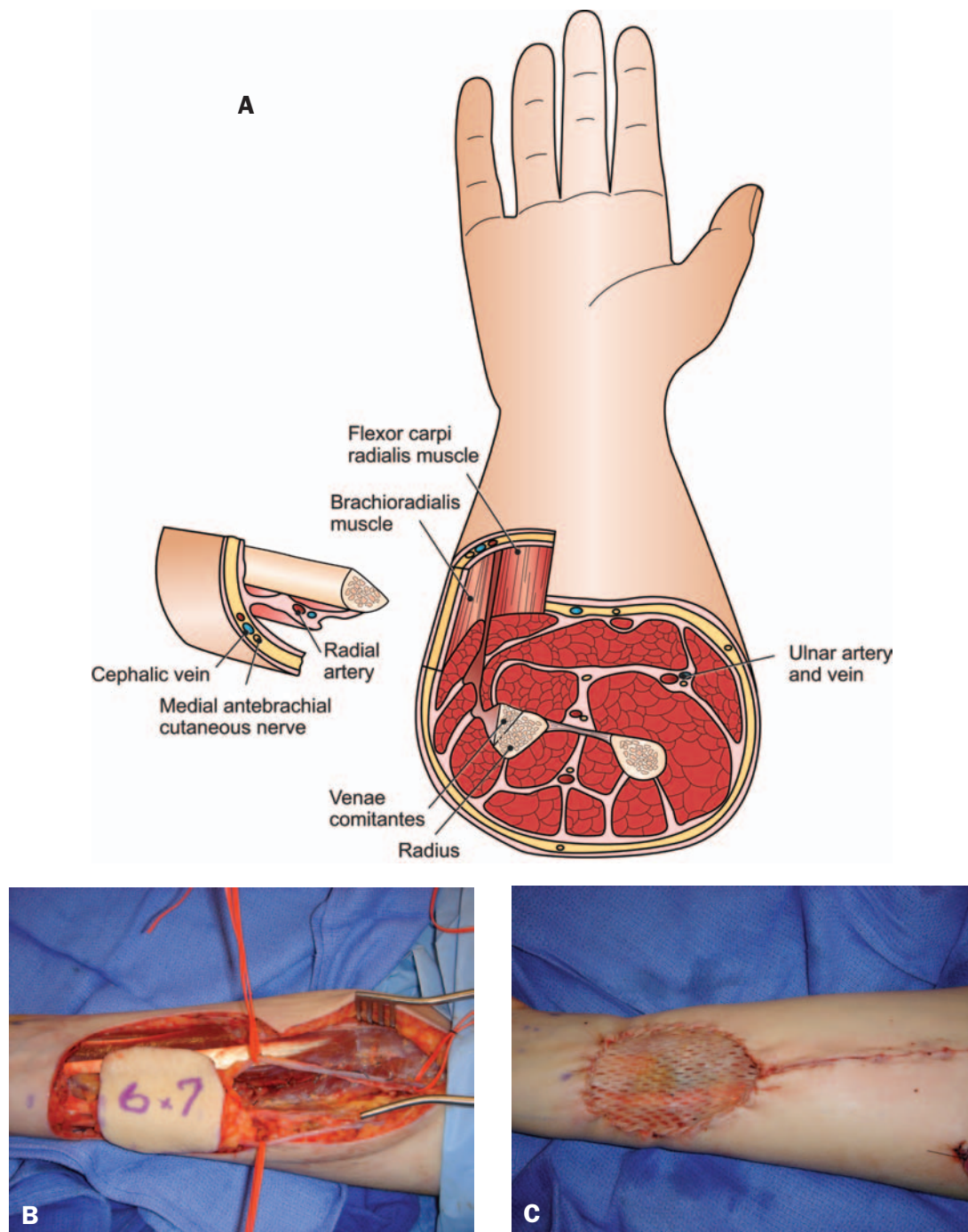


FIGURE 50-12 Radial forearm fasciocutaneous free flap. A, Regional anatomy; B, harvest; C, donor-site skin graft.

reconstruction, used for a variety of soft tissue defects of the head and neck, with excellent predictability and acceptable morbidity.

Technique for Radial Forearm Free Flap Harvest

The area of skin paddle harvest should be outlined, along with the planned incision (see Figure 50-12B). The axis of the flap should be centered over the radial artery and cephalic vein. Allen's test is reconfirmed with a Doppler probe on the radial aspect of the thumbs. Flap harvest should be performed under 250 mm Hg of tourniquet compression, and dissection begins distally to locate the radial artery and venae comitans. The vascular pedicle lies between the flexor carpi radialis and the brachioradialis. The radial aspect of the skin flap is initially raised. After incision of the skin, the cephalic vein is identified and maintained with the skin paddle. The cephalic vein may be dissected along its full length at this time and protected with moist sponges. As the radial aspect of the skin paddle is elevated to the level of the intermuscular septum, the superficial branch of the radial nerve is identified and must be preserved to maintain the sensation to the dorsum of the hand. The ulnar side skin flap is now raised in a subfascial plane. Fascia between the brachioradialis and the flexorcarpi radialis is incised carefully, exposing the underlying pedicle. The radial vascular bundle and cephalic vein may now be divided and ligated at the distal extent. The vascular pedicle can be lengthened as needed by tracing the radial artery proximally. The tourniquet is released, and the flap is allowed to reperfuse for 20 to 30 minutes before harvest. The flexor muscle bellies are pexied on themselves in the distal forearm to allow skin grafting and prevent tendon exposure. Once the RFFF is harvested, the donor site is closed with a split-thickness skin graft (see Figure 50-12C). The harvested tissue is inset into the defect, with care taken to preserve the vascular pedicles (Figure 50-13). A vacuum-assisted dressing is applied to the donor site and allowed to remain in place for 5 to 6 days.

Fibular Osteocutaneous Free Flap

Ueba and Fujikawa of Japan and O'Brien and Morrison in Australia have been credited with independently recognizing the potential of the fibula for microvascular transport based on the peroneal vessels and their lateral branches.^{62,242} Taylor and colleagues subsequently used it to reconstruct the lower extremity.²⁴³ Gilbert simplified the technique by developing a lateral approach, similar to the one that is used today.⁶⁴ The utility of the free fibular osteocutaneous flap (FFOF) for mandibular reconstruction was recognized and subsequently popularized by Hidalgo in 1989.⁶⁶ Since that time, a series of surgeons

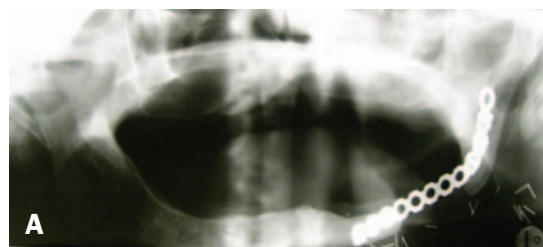


FIGURE 50-13 A 92-year-old patient following composite resection of the floor of the mouth and mandible for squamous cell carcinoma immediately reconstructed with a radial forearm fasciocutaneous free flap and reconstruction plate. A, Postoperative panoramic radiograph; B, intraoral appearance; C, postoperative facial appearance.

throughout the world have shown the FFOF to be a highly reliable flap for reconstruction of mandibular continuity defects.^{75,78,79,82,85,87-90,103,107,117-121,123-125,244} Widespread dissemination of technical expertise in microvascular surgery has resulted in almost complete abandonment of nonvascularized bone grafts in most major centers for cancer-related composite tissue defects. The fibula has a thick outer cortex that provides up to 22 to 25 cm of bone for use in reestablishing continuity of the mandible and can be transferred as an osteocutaneous or osteofascial flap. The advantages of the fibula osteocutaneous flap are that its constant topography provides ease of harvest that can be performed simultaneously with head and neck extirpative procedures with little donor-site morbidity and adequate bone stock to place dental implants.⁹⁰ The disadvantages are that the vascular pedicle is relatively short, the bone height is one-third the height of the native dentate mandible, and the skin paddle can be bulky in relation to implant emergence and rehabilitation with prosthetics. At our institution, the FFOF has become the most commonly used donor site for reconstruction of continuity defects of the mandible. Although not quite as suitable as the RFFF, it provides adequate soft tissue quality for most oral and oropharyngeal applications.

Technique of Fibular Osteocutaneous Flap Harvest

The patient is placed in the supine position with the ipsilateral knee bent and stabilized with a hip and foot roll. Skin paddle septocutaneous perforators are identified at the junction of the distal and middle third of the leg with a Doppler probe. The tourniquet is inflated to 350 mm Hg, and the incision is outlined from the fibular head to the lateral epicondyle of the ankle. If a skin paddle is to be harvested, it is centered over the previously identified perforator between the middle and the lower third of the lower leg. The dissection begins anteriorly by incising skin and subcutaneous tissue. The investing fascia over the peroneus longus and brevis is incised, and the skin paddle is bluntly elevated to the intermuscular septum. The peroneus longus is sharply excised from the fibula, leaving a 2 mm muscle cuff to ensure periosteal viability. The deep peroneal nerve is identified as it crosses the fibular head and is protected. Further medial dissection exposes the interosseous membrane. The extensor hallucis longus is released, and right-angled hemostats are placed around the site of the distal and proximal osteotomies. Osteotomies are performed with a sagittal saw. A bony window is removed at each site to allow better access to the vascular pedicle. The distal extent of the pedicle is identified, ligated, and divided. The interosseous septum is divided

distally to proximally, and the fibula is allowed to roll laterally. The posterior aspect of the skin paddle is incised and elevated to the septum. A cuff of soleus and flexor hallucis longus is included. The pedicle is then dissected in a distal to proximal direction (Figure 50-14A). The posterior tibial muscle is then incised proximally along the course of the peroneal vessels. The fibula may be contoured by a series of osteotomies in vivo or when harvested (Figure 50-14B). A split-thickness skin graft is applied to the skin paddle donor site if skin has been harvested. Avoid primary closure of the donor site owing to the risk of compartment syndrome. A posterior splint is applied to the donor site, and physical therapy is initiated 3 days after surgery.

Technique for Inset of the Fibular Flap

A two-team approach consisting of an ablative surgeon and a microvascular surgeon is used to minimize operating time and improve efficiency. Following neck dissection, the composite tissue resection is performed by the ablative team and the proximal and distal bony segments are stabilized with a reconstruction plate if possible. Various techniques have been used to assist in stabilization of the proximal and distal bony segments. A 2.4 or 2.0 mm locking reconstruction

plate is prebent in the shape of the native mandible based on the planned osseous resection using a prefabricated, custom stereolithographic model (Figure 50-15). It is preferable to adapt and apply the plate to the mandible prior to the planned osteotomies if oncologically sound (Figure 50-16). In situ bending and preosteotomy plate application are not possible in patients with tumor involving the buccal mucosa if one is to excise the specimen en bloc. In the absence of a stereolithographic model, one method of positioning the reconstruction plate after segmental mandibulectomy is by identifying the facial midline and the relationship of the reconstruction plate to the maxillary arch. The dentate patient is placed into intermaxillary fixation, and the reconstruction plate is applied. The proximal and distal segments are stabilized with a minimum of three and preferably four locking screws placed in a bicortical fashion under copious irrigation. The ablative hard and soft tissue defect is measured, and the appropriate skin paddle is outlined. The osteofasciocutaneous flap is harvested by the microvascular surgeon, and the fibula is then prepared for inset. Mitered wedge osteotomies are positioned as needed to create a central anterior segment that ranges in length from 2 to 3 cm (see Figure 50-16B). The vascular pedicle is elevated



FIGURE 50-15 Preoperative stereolithographic model used to prebend the reconstruction plate.

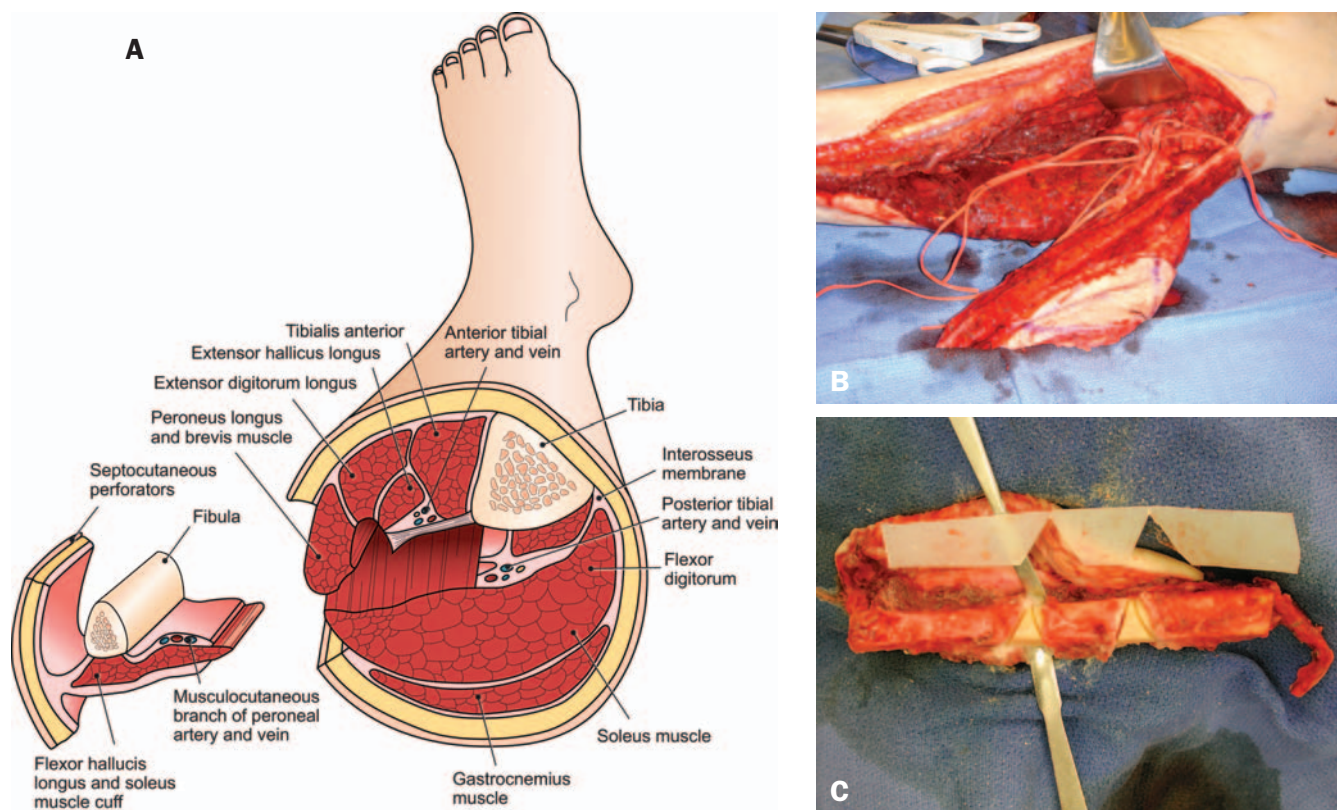


FIGURE 50-14 Fibular osteofasciocutaneous free flap. A, Regional anatomy; B, harvest; C, mitered wedge osteotomies.

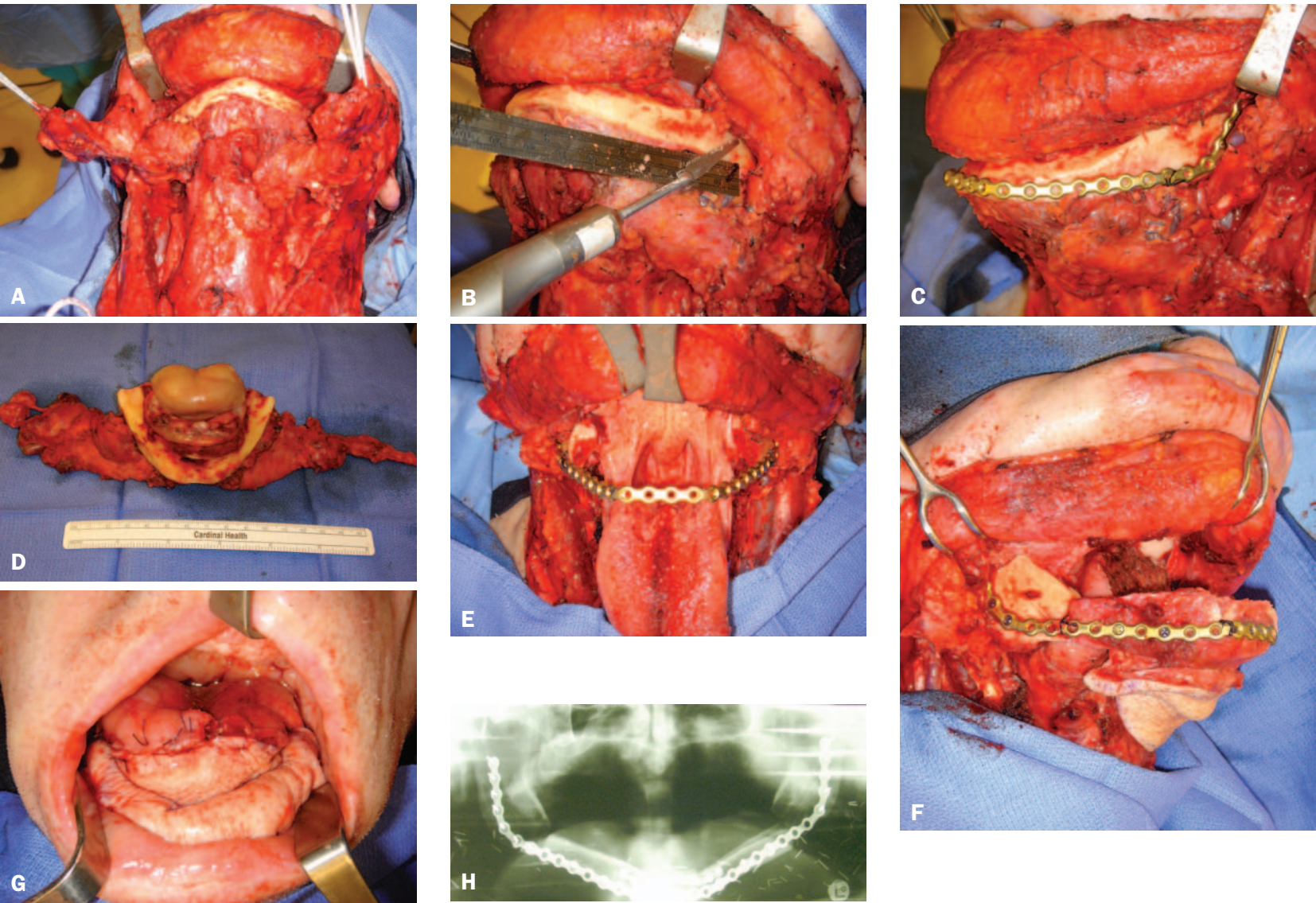


FIGURE 50-16 Reconstruction of the mandible with a fibular osteocutaneous free flap following composite resection of the anterior floor of the mouth, tongue, and mandible. *A*, Approach to the mandible via a horizontal neck incision with the contents of the neck dissections attached to the mandible and prepared for the en bloc resection; *B*, the mandible is contoured to better receive the reconstruction plate and minimize the number of fibular osteotomies; *C*, the prebent reconstruction plate is adapted to the mandible and temporarily stabilized with screws in anticipation of the planned mandibular osteotomies; *D*, surgical specimen following removal of the reconstruction plate; *E*, the reconstruction plate is readapted to the native mandible and stabilized with locking screws placed in a bicortical fashion; *F*, the neomandible is formed by adapting the fibula to the reconstruction plate; *G*, the skin paddle is passed into the oral cavity and sutured to the surrounding soft tissue; *H*, postoperative panoramic radiograph.

from the medial aspect of the fibula in the areas of the wedge osteotomies, protecting the pedicle from the reciprocating saw. Perfectly mitered joints are less important than expedient surgery. The lateral segments are then trimmed to reconstruct the defect accurately, according to measurements previously taken from the surgical specimen and the reconstruction plate. If a reconstruction plate is not available, these measurements include the running length of the specimen at the inferior border and the transverse measurement from one stump across to the other. Once these measurements have been reproduced in the construct, the fibula is adapted to the reconstruction plate and stabilized with monocortical locking screws (Figure 50-17A). Alternatively, the

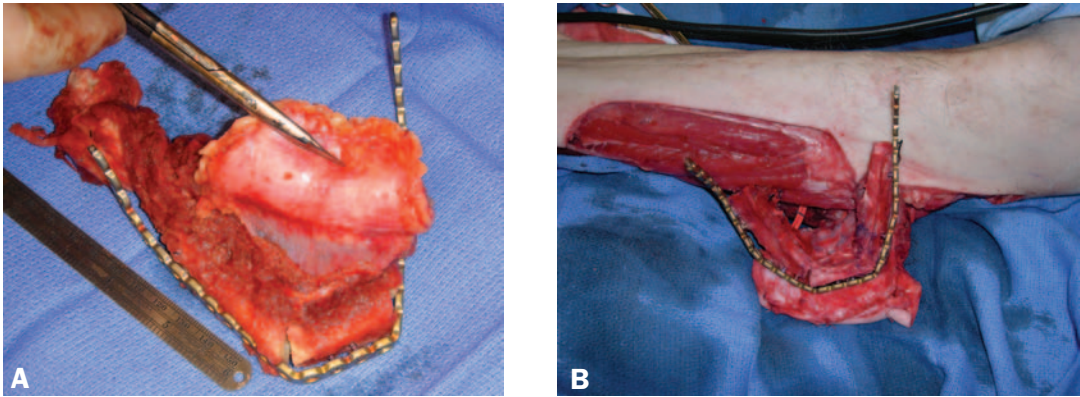


FIGURE 50-17 Attachment of the fibula to the reconstruction plate. *A*, The flap is separated from its blood supply and is inset into the construct on the back table; *B*, the flap is inset into the metal construct while attached to its blood supply.

fibula can be shaped to fit the reconstruction plate on the back table while maintaining vascular perfusion (Figure 50-17B). The recipient vessels are prepared for the microvascular anastomosis, and the skin paddle is then inset into the adjacent soft tissues using 3-0 Vicryl sutures. Although watertight closure of the oral cavity is desirable, it is not absolutely necessary for successful wound healing. If an additional external skin paddle is required, the intervening skin can be deepithelialized, allowing one skin paddle to serve both locations. The skin paddle is drawn from the lingual aspect over the neoalveolar ridge into its final position with the vascular pedicle lying on the inferior border of the neomandible. The microvascular anastomosis is performed under a surgical microscope of $\times 10$ power, using microinstruments with a low closing pressure and an 8-0 suture. The microvascular arterial anastomosis is generally performed in an end-to-end fashion into a branch of the external carotid artery (Figure 50-18). The venous anastomosis is generally performed in an end-to-side fashion into the internal jugular vein. Atraumatic tissue handling is important to minimize intramural coagulation, as is the liberal use of topical dilators and heparin. No systemic heparin or colloid solution is routinely given to the patient. Postoperatively, the patient is treated with aspirin to minimize platelet aggregation. Perioperative corticosteroids are frequently used to minimize perioperative edema.

Treatment outcome: Microvascular Free Tissue Transfer

More than 15 years have elapsed since the introduction of microvascular surgery to head and neck reconstruction, and a number of studies with large series of patients demonstrate that, in experienced hands, the success rate for reestablishing mandibular continuity is greater than 90%.^{75,82,85,87,90,91,107,119-125,245} Perioperative complication rates range from 9 to 85% depending on the definition of complication and the patient population.^{75,82,85,87,90,91,107,119-125,245} Surgical

reexploration for ischemic flaps occurs less than 10% of the time, and salvage rates have been reported to be between 50 and 70%. Mortality is generally no greater than any other major surgical procedure in age- and performance-matched patient populations, ranging from 0.5 to 6.5%. Importantly, radiation therapy does not seem to affect flap survival or the number of complications (see below).

Outcome studies for mandibular reconstruction in general and microvascular free flap reconstruction in particular have been limited. The quality of the existing literature is generally poor (level IV evidence) and contains significant variations with regard to inclusion criteria, data analysis, and follow-up. Additionally, few studies present objective measures of patient function and satisfaction with the outcome. Important measures that should be addressed in any reconstructive endeavor include QOL, appearance, sensation, motor function (speech and swallowing), donor-site morbidity, skeletal support, complications, and cost.²⁴⁶

A number of studies have validated the use of QOL instruments in head and neck reconstruction and have demonstrated consistent relationships between QOL and clinical measures such as tumor stage, age, tumor site, and stage-specific treatment.^{113,247} Patients undergoing microvascular surgery in particular have been shown to exceed pretreatment QOL values by 1 year. QOL studies may be considered a rationale for extensive ablative procedures in light of current reconstructive standards. Because appearance is a subjective finding, QOL studies have attempted to include this parameter in their questionnaires. Sensation is another important component that is often subjective in nature and has been shown to make a positive impact on patient function and satisfaction. Urken demonstrated the ability for radial forearm free flaps to be reinnervated when the lateral antebrachial cutaneous nerve has been anastomosed to a recipient nerve.²⁴⁸ Although the impact of peripheral innervation and increased operative times have slowed universal acceptance of routine neuroanastomoses, these studies emphasize the importance of examining a parameter with respect to function.

The functional aspects of reconstructive procedures as they relate to composite tissue defects are important but challenging to qualify and objectively measure. Swallowing has been shown to be superior in primary tongue reconstruction when compared with delayed or secondary reconstruction.²⁴⁹ Additionally, repair of tongue defects has been identified as the most important predictor of functional outcome in the reconstruction of mandibulectomy defects.²⁵⁰ The radial forearm probably represents the most functional soft tissue reconstruction, the design of which can be

altered to optimized oral cavity defect closure while preserving the lingual shape and mobility of the tongue. Salibian and colleagues showed that the tongue base function, proximity of the reconstructed tongue to the palate, and surface area of the floor of the mouth are the most important factors in favorable functional outcome.²⁵¹ Furthermore, larger defects require bulkier flaps to improve swallowing and optimize airway protection.

The need for mandibular reconstruction is fairly well established. Although bite force comparisons for patients undergoing microvascular reconstruction are generally less favorable than unoperated controls, mandibular continuity does result in better function than seen in unreconstructed patients.²⁵² Lateral defects appear to be the least detrimental in terms of esthetics and dysfunction, and they continue to be managed in a variety of methods, including no reconstruction, a plate with or without a myocutaneous flap, nonvascularized bone grafts, distraction osteogenesis, or free flaps. Controversy remains, however, with regard to the most appropriate method for establishing continuity in the anterior or symphyseal defect. Vascularized bony reconstruction appears to offer the advantages of predictable and immediate restoration of mandibular form and function that is superior to previously described techniques.¹³⁷

Advocates of microvascular free tissue transfer often point to the lower rate of complications seen when compared with the era of pedicled regional flaps, when there appear to have been significant problems related to predictability. Partial flap loss, donor-site morbidity, gravitational issues, and fistulization were commonplace and prompted the acceptance of free flaps. Based on the existing literature, it seems that microvascular surgery has improved the complication rates that were seen previously,²⁵³ but it may have done so at increased cost and resource use.²⁵⁴ Standardized data collection methods, multi-institutional, and, indeed, multispecialty cooperation will be necessary before many of these questions can be definitively answered.

Distraction Osteogenesis Distraction osteogenesis has been widely used in long bones for several decades; however, its relatively recent introduction into craniofacial reconstruction has added an important new tool in the armamentarium of surgeons managing patients with complex mandibular deficiencies.⁹⁴⁻⁹⁶ By means of this technique, new bone is created after an osteotomy followed by gradual separation of the bony fragments, and several authors have used these principles for the reconstruction of segmental mandibular defects.²⁵⁵⁻²⁶⁴ The experimental and clinical aspects of osteodistraction are described elsewhere in this text and are beyond the scope of this chapter. The existing body of

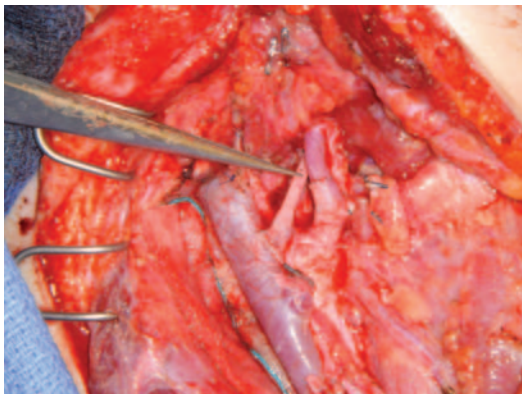


FIGURE 50-18 Microvascular anastomosis.

world literature, as it relates to transport distraction, consists wholly of case reports or very small case series. Although the most predictable indications are still being defined, it does have some already well-established limitations related to the reconstruction of segmental mandibular defects. Questions remain regarding the efficacy of gradual distraction in patients who have had or will have radiation therapy, those with long, curvilinear defects, those with significant soft tissue loss, and those with a severely atrophic mandible or one at risk of pathologic fracture. It is likely that the indications for the distraction of mandibular continuity defects will be similar to those currently recommended for nonvascularized bone grafts (ie, short bony defects associated with benign disease); however, further elucidation is required. The remainder of this chapter attempts to provide a rational approach to the reconstruction of segmental mandibular defects by individualizing the reconstruction based on the anatomy of the defect and the clinical characteristics of the various reconstructive modalities.

Disease-Related Considerations

The choice of technique in oromandibular reconstruction depends partly on the disease process that afflicts the patient-acquired (benign, malignant, or post-traumatic), developmental, or congenital defect and partly on the anatomy and character of the defect resulting from therapy. The latter relies more specifically on the type of defect as it relates to (1) the length of the bony deficiency, (2) the location of the bony deficiency, (3) the presence of an intraoral mucosal or external skin soft tissue deficiency, and (4) the tissue bed integrity (vascularity). For the purposes of this chapter, we have restricted discussion to that of acquired mandibular defects.

Length and Location of the Defect

The importance of defect length has been discussed previously. Studies by Foster and colleagues,¹⁸⁶ Pogrel and colleagues,¹⁸⁷ and August and colleagues,¹⁸⁸ clearly demonstrate that defects beyond 6 to 9 cm are more predictably reconstructed using free tissue transfer.

A second important factor involved in planning mandibular reconstruction is the location of the defect. Based on the functional forces applied by the suprahyoid musculature, the muscles of mastication, and the dentition, we identified three distinct anatomic units that aid the surgeon in choosing a particular reconstructive modality: the (1) ramus-condyle unit; (2) body unit, and (3) symphysis unit.

Ramus-Condyle Unit (Posterior Defect)

The ramus-condyle unit includes the mandibular ramus, angle, and temporomandibular joint. It is involved in mastication and provides bulk, facial

contour, and continuity. Acquired or congenital loss of this segment results in decreased posterior facial height, malocclusion, and facial asymmetry. Reconstruction may be accomplished by costochondral grafts, fibular osteocutaneous free flaps, custom alloplastic prostheses, or second metatarsophalangeal joint replacement. In the context of a lateral resection for malignant disease, however, the ramus-condyle unit must be incorporated into the overall reconstruction. Several techniques have been described for the management of loss of the condyle. Prosthetic condylar implants were widely used at one time; however, problems with erosion into the glenoid fossa, particularly in the radiated patient, have limited their use to a temporary measure. A more contemporary option in fibular transplantation is to shape the end of the free flap into a replica of the condyle (Figure 50-19). Functional results in this technique are

dependent on the precision in which the neocondyle is inset into the glenoid fossa. In our experience, even patients in whom the neocondyle is inadvertently placed out of the fossa may retain excellent functional and esthetic results with a stable occlusion. Our preferred method of condylar reconstruction in restoring mandibular continuity with free flaps is by autotransplantation of the native condyle.²⁶⁵ The condyle is rarely involved in malignant or benign pathologic processes, and it has been shown that condylar autotransplantation is safe and effective. The native condyle is stabilized to the neomandible either in situ or on the back table using plates and screws or wire fixation. Condylar autotransplantation should be considered in all cases in which the condyle can be preserved without violating oncologic principles (Figure 50-20).



FIGURE 50-19 Patient with a defect of the posterior mandible resulting in loss of vertical dimension, malocclusion, and facial disfigurement. A, Preoperative appearance; B, preoperative panoramic radiograph; C, fibular construct prior to inset into the patient; D, postoperative panoramic radiograph following implant-supported prosthetic rehabilitation; E, postoperative appearance.

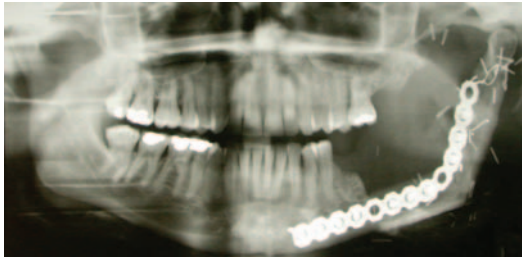


FIGURE 50-20 Panoramic radiograph demonstrating autotransplantation of the native condyle to the neomandible (fibula).

Body Unit (Lateral Defect)

The body unit includes lateral mandibular defects and provides bulk and support for teeth. It is less important in facial form and contour and is thus the easiest to reconstruct. Most patients with composite defects will benefit from the use of a fibular osteofasciocutaneous flap. A small subset of patients with no significant soft tissue defect, such as those undergoing resection for benign disease, can be managed with a fibular osteofascial flap. Deep circumflex iliac artery (DCIA) flaps have the advantage of vertical height that approaches the native mandible and are therefore useful in adult, fully dentate patients with isolated lateral mandibular defects. Pediatric patients or those adults with benign disease and segmental defects less than 6 cm in length are candidates for nonvascularized bone grafts or distraction osteogenesis (Figure 50-21). Patients with an extremely poor prognosis or those medically unsuitable for major microvascular surgery may be left unre-

constructed or paliated with a reconstruction plate, with or without a local or regional soft tissue flap.

Symphysis Unit (Anterior Defect)

The symphysis unit involves anterior mandibular defects and is the most complex area of the mandible (curved). It serves as a lever arm and the site of attachment for the mylohyoid, geniohyoid, digastric, mentalis, buccinator, genioglossus, and other tongue musculature. It has a vital function in maintaining airway patency and is the most difficult to reconstruct. As previously mentioned, nonvascularized bone grafts require delayed reconstruction: reconstruction plates without bone have high failure rates for continuity defects of the anterior mandible. For these reasons, most segmental defects involving the anterior arch are reconstructed using vascularized free flaps (Figure 50-22).

The vascular quality of the tissue and the quantity and location of the soft tissue defect play a critical role in determining the appropriate reconstructive modality. The restoration of intraoral mucosal or external facial defects is also paramount to restoring speech, swallowing, oral competence, and appearance. Oncologic resection usually includes substantial amounts of oral soft tissues, and these defects predispose patients to wound-healing problems, dysarthria, and/or dysphagia. As previously discussed, swallowing has been shown to be superior in primary tongue reconstruction when compared with delayed or secondary reconstruction and repair of tongue

defects has been identified as the most important predictor of functional outcome in the reconstruction of mandibulectomy defects. Inadequate mucosal replacement leads to increased complications such as infection, bone and hardware exposure, orocutaneous fistula, and carotid blowout. A number of reconstructive options exist depending on the clinical situation and the need for accompanying bone. Soft tissue preparation must often occur prior to nonvascularized bone grafting in an effort to optimize the soft tissue envelope, bulk, and vascularity of the recipient bed. Previously, this was accomplished using various pedicled regional flaps, such as the pectoralis major myocutaneous flap. Contemporary reconstruction, however, involves microvascular free tissue transfer, and we prefer the radial forearm flap for most isolated soft tissue ablative defects involving the oral cavity or oropharynx. Composite tissue defects are more complicated, and the options for immediate reconstruction are limited to the various composite tissue free flaps. Whereas the DCIA, scapular, and radial forearm osteofasciocutaneous flaps have been advocated by various surgeons, the fibular free flap is our primary choice and has been shown to provide adequate bony length and height with sufficient soft tissue bulk and a reliable skin paddle.

Management of the Irradiated Patient

The tissue of patients who have undergone radiation therapy is hypocellular, hypovascular, and hypoxic. As discussed earlier, conventional mandibular reconstruction using nonvascularized bone grafts in irradiated patients has resulted

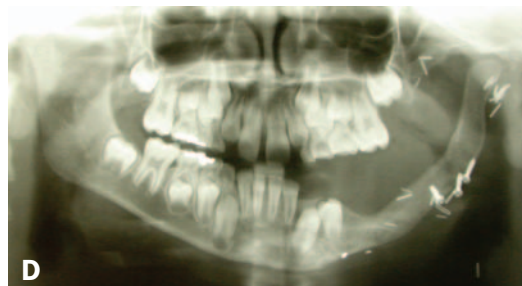
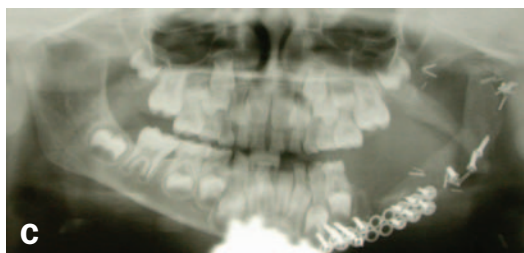
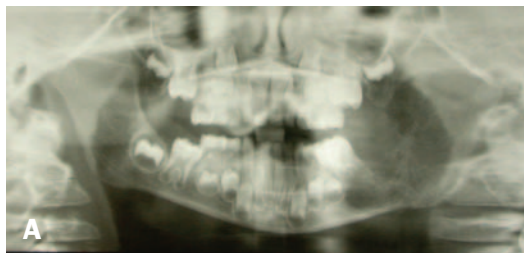


FIGURE 50-21 A 6-year-old patient with Ewing's sarcoma. A, Preoperative panoramic radiograph; B, intraoperative photograph of an anterior iliac crest bone graft; C, immediate postoperative panoramic radiograph; D, 3-year postoperative panoramic radiograph; E, postoperative appearance.

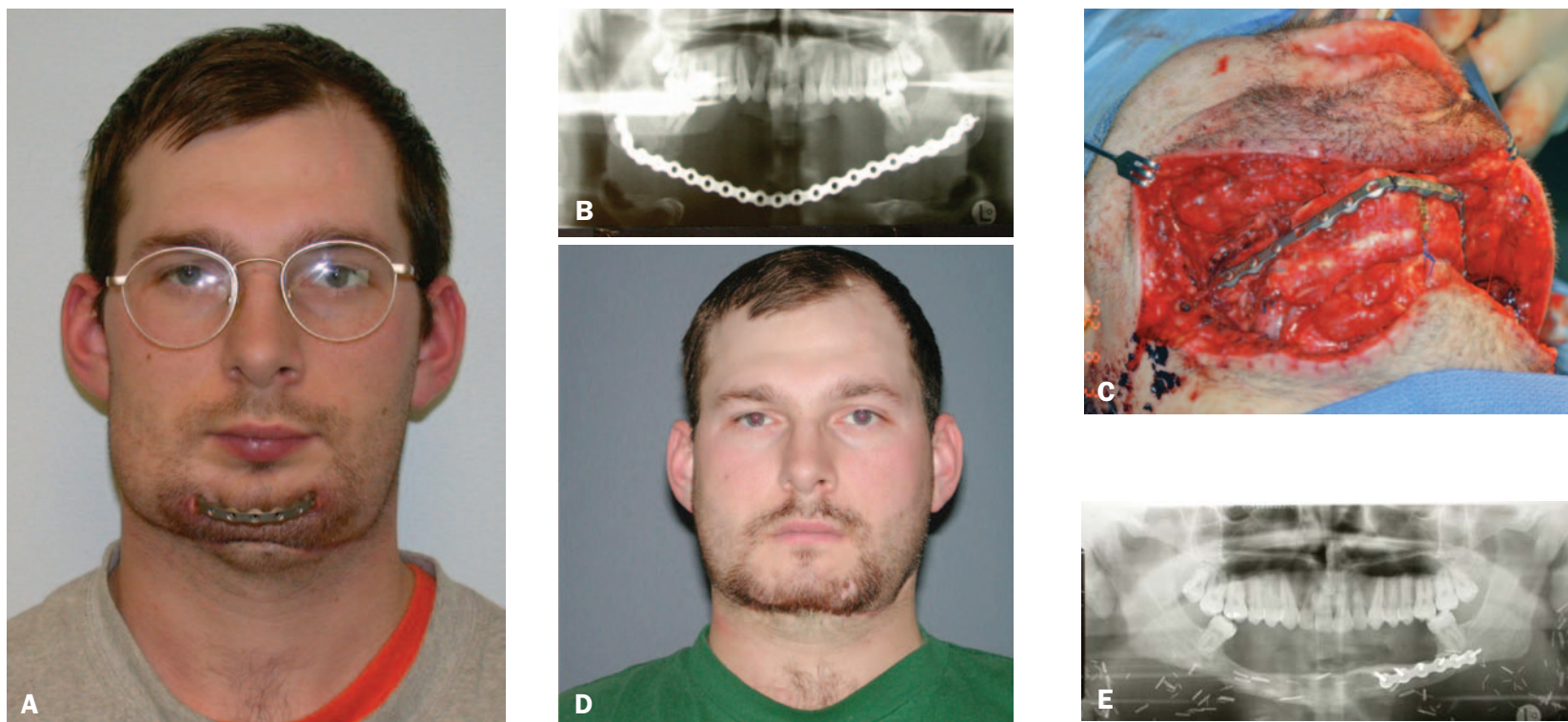


FIGURE 50-22 A 25-year-old patient with an exposed reconstruction plate after angle-to-angle mandibular resection for a benign jaw tumor. A, Preoperative appearance; B, preoperative panoramic radiograph; C, intraoperative photograph following inset of the fibular osteofascial free flap; D, postoperative appearance; E, postoperative panoramic radiograph.

in unfavorable success rates and is associated with high complication rates. Morbidity associated with radiation therapy is considerable and includes poor wound healing, xerostomia, hair loss, mucositis, radiation caries, trismus, and ORN. Marx and Ames popularized the use of HBO as an adjunct in managing irradiated tissue.⁵⁸ HBO enhances perfusion in irradiated tissue and allows it to heal and support nonvascularized bone grafts. Twenty HBO treatments preoperatively (100% oxygen at 2.5 atm for 90 minutes) followed by 10 treatments postoperatively resulted in success rates of 92%. As previously stated, however, we prefer to reconstruct patients immediately at the time of ablative surgery. Therefore, our reconstructive modality of choice is vascularized composite tissue flaps harvested from the fibula.

Questions have also arisen with regard to the effect of radiation therapy on microvascular free tissue transfer, and the true effect on complications and flap survival is not definitively known. Radiation therapy has the potential to damage small vessels and may adversely affect microvascular anastomoses. Specific vascular damage has been demonstrated and includes diminished smooth muscle activity, endothelial cell dehiscence, and vessel wall fibrosis.^{266,267} Clinical and experimental studies have come to divergent conclusions. In an experimental study in rabbits, Krag and colleagues showed that administering radiation to recipient vessels before surgery significantly increased free flap failure rates.²⁶⁸

Furthermore, in a clinical study, Deutsch and colleagues reported a higher complication rate in patients receiving preoperative or postoperative radiation and concluded that the timing of the radiation did not affect complications.²⁶⁹ Other experimental studies performed in rats, however, found that radiating recipient vessels before surgery did not adversely affect free flap viability.^{270,271} Indeed, the preponderance of clinical evidence suggests that radiation therapy does not affect the rate or severity of local complications after free tissue transfers.²⁷² Choi and colleagues found no correlation between complications and total radiation dose, size of the radiation field, disease stage, exposure to chemotherapy, the presence of serious medical comorbidities, patient age, or history of tobacco use.²⁷³ Our own experience with more than 300 microvascular reconstructions suggests that there is no difference in flap survival or complications among irradiated patients compared with unirradiated controls and that reconstruction following concomitant chemoradiotherapy has no significant effect on reconstructive outcomes.²⁷⁴

Special Considerations

Advanced ORN

Advanced mandibular ORN continues to pose unique challenges to the maxillofacial reconstructive surgeon. ORN was originally thought to arise in the presence of radiation, trauma, and infection.²⁷⁵ Marx later proposed the widely

accepted theory that radiation caused an endarteritis that results in tissue hypoxia, hypocellularity, and hypovascularity, which, in turn, causes tissue breakdown and chronic nonhealing wounds.¹⁹⁰ This theory has been the basis for using HBO for prevention of ORN²⁷⁶ and for the use of HBO, either alone or combination with surgical débridement to treat ORN.^{58,277,278}

The Marx protocol has resulted in an approximately 5% incidence of ORN following post-radiation dental extractions.²⁷⁶ A series of more contemporary studies, however, have questioned the effectiveness of HBO in preventing ORN by demonstrating post-radiation therapy dental extraction rates of ORN equal to or less than that reported by Marx, without the use of HBO.^{279–281} The concept of HBO as effective adjuvant therapy for existing ORN has also been challenged. Annane and colleagues conducted a randomized, placebo-controlled, double-blind study to compare HBO over placebo in the treatment of ORN.²⁸² All patients had at least one clinical and one radiologic sign of ORN. Patients with advanced ORN, defined as those with a pathologic fracture or an orocutaneous fistula, were excluded. Sixty-eight patients were randomized into HBO and placebo groups and evaluated for their response to therapy. The investigators noted worse outcomes in the HBO group (19% response) than in the placebo group (33% response), and the trial was terminated prematurely because of failure to demonstrate any benefit of HBO in recovery, disease progression, or pain relief.

There is new evidence to suggest that additional factors are involved in the etiology of this disabling condition. It is thought that osteoclasts suffer radiation effects earlier than vascular alteration and that suppression of bone metabolism is a critical component in the development of ORN.²⁸³ Osteocyte devitalization has been observed in both ORN and bone that was recently irradiated.²⁸⁴ The relation of ORN to bisphosphonate osteonecrosis of the jaws is enigmatic, but the similarities are striking.²⁸⁵ It has been proposed that ORN arises from a fibroatrophic process that occurs as a result of reactive oxygen and the deregulation of fibroblast proliferation and metabolism.²⁸⁶ This theory has been the basis for using antioxidants and antifibrosis drugs for the treatment of ORN. Futran and colleagues investigated the efficacy of pentoxifylline for radiation therapy-related soft tissue necrosis, fibrosis, and mucosal pain.²⁸⁷ They found favorable responses for fibrosis and soft tissue necrosis but little effect in halting bone necrosis. More recent studies have observed significant disease regression symptom control using pentoxifylline-tocopherol.^{288–290} However, once the tissue necrosis progresses to the point of fistulization or pathologic fracture, it is clear that surgical resection of the nonviable tissue remains the hallmark of treatment.

The principles of bony reconstruction following resection for advanced ORN remain the same for segmental defects of any etiology. The segmental mandibular defect resulting from an appropriate resection of ORN is abuted by irradiated but viable bone stumps. The interface between the reconstruction and native bone must be covered by intact, vascularized soft tissue for osteosynthesis to predictably succeed. The concept of patient selection in ORN surgery is a rare luxury. These patients are often in pain and are highly motivated to proceed with resection. They frequently suffer from medical comorbidities that complicate perioperative care. Their history of head and neck cancer is often associated with poor nutrition, and preoperative nutritional preparation should be considered.

The soft tissues that surround the ORN defect bear the permanent sequelae of radiation and are deficient both qualitatively and quantitatively. They cannot be extensively dissected, stretched, or otherwise manipulated to provide coverage and must lie passively over the osseous reconstruction. The use of soft tissue flaps and HBO therapy prior to conventional bone grafting of ORN defects has been discussed. The preliminary insertion of a regional flap of vascularized soft tissue such as a pedicled pectoralis major or latissimus dorsi flap, followed by a period of healing, allows the creation of a better soft tissue bed for subsequent conventional grafting. The prolonged treatment time associated with delayed bone grafting and the development of more

contemporary microvascular procedures have resulted in little contemporary advocacy for this approach.

Microvascular free flap reconstruction of ORN defects offers many advantages over multi-stage soft tissue and hard tissue reconstruction, not the least of which is single-stage surgery. A composite flap, such as the fibula, allows reconstruction of both hard and soft tissue elements of the defect, bringing nonradiated tissue with its independent blood supply into the hypoxic and fibrotic wound (Figure 50-23). Several studies have demonstrated highly successful results without the use of HBO,^{291–297} and at least one study found fewer complications in

patients not treated with HBO.²⁹⁸ Our own experience has been the overall flap survival, and complications are no more frequent in ORN patients than those found in radiated patients or in unirradiated controls.²⁹⁷ Regardless of the technique of reconstruction, the ORN patient is significantly more complex than reconstruction following benign tumor excision, and we highly recommend the use of free tissue transfer.

Restoration of Functional Occlusion

Reconstruction of continuity defects of the mandible is only part of the goal. Ultimately, patients who are free of disease should and can be

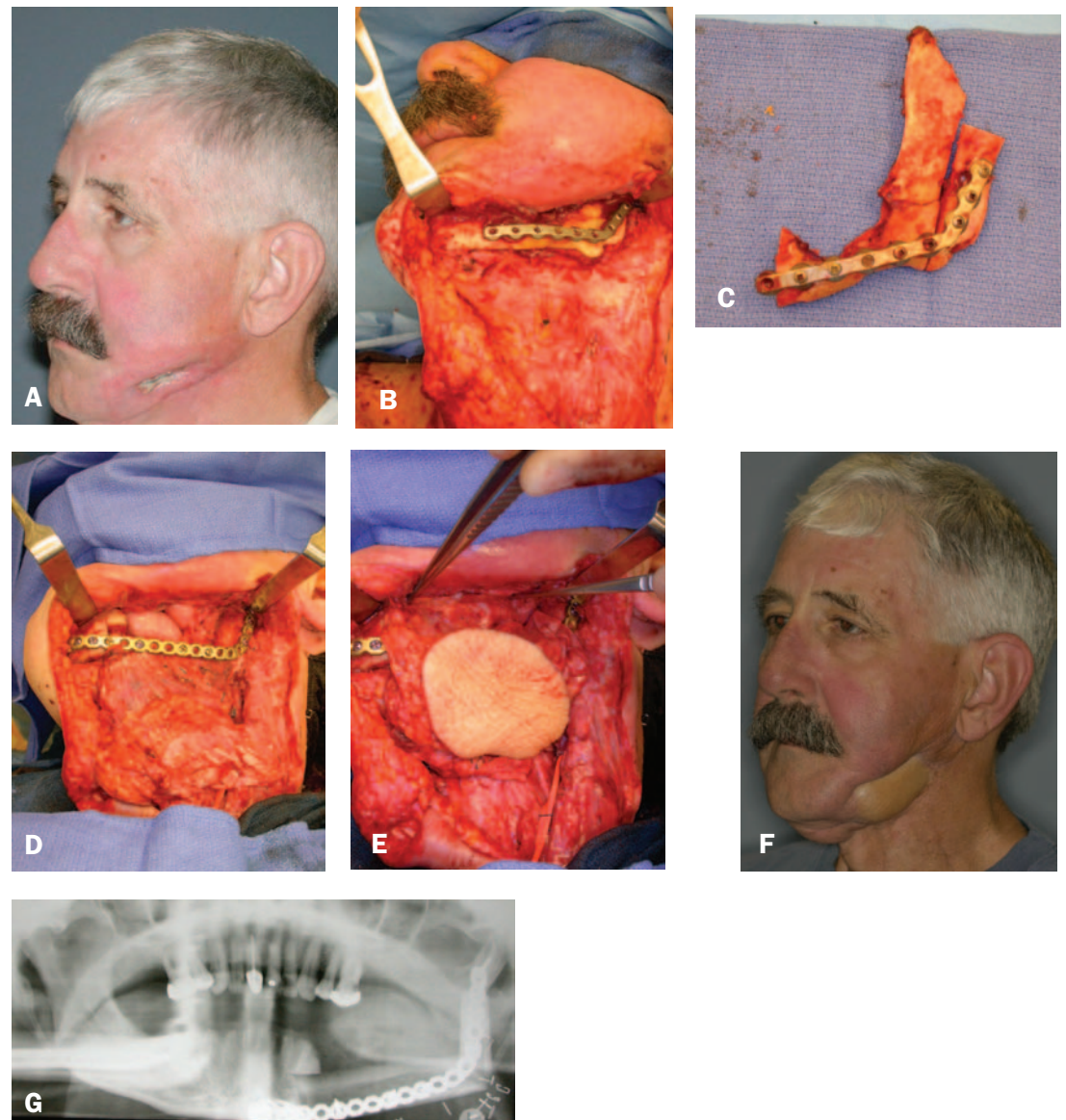


FIGURE 50-23 A 57-year-old patient with osteoradionecrosis of the mandible following surgery and adjuvant radiation for oral cavity cancer. A, Preoperative appearance demonstrating exposed, necrotic bone and a previously placed reconstruction plate; B, surgical approach; C, surgical specimen; D, application of the reconstruction plate; E, inset of the fibular osteofasciocutaneous flap prior to deepithelialization of the skin paddle, which is used to line both intraoral and facial tissues; F, postoperative appearance; G, postoperative panoramic radiograph.

restored to a more normal functional occlusion. Occasionally, occlusion may be successfully restored using conventional removable prosthetics (Figure 50-24). This is useful in patients with skin paddles that remain in place. More ideally, osseointegrated implants may be used to facilitate prosthetic rehabilitation (Figure 50-25). The placement of osseointegrated implants into bone flaps or grafts is becoming more predictable but has significant challenges.²⁹⁹⁻³⁰⁴ The requirements for successful osseointegration are the availability of adequate soft tissue coverage over the bone (preferably mucosa), a vertical height of bone of at least 7 to 10 mm, and a bone width of at least 5 to 6 mm. The fibula fits these requirements but only marginally. Most of the criticisms of the fibula flap in regard to osseointegrated dental implants relate to the vertical height of bone, which is often inadequate for younger patients with a full dentition. Although not a significant

problem in elderly edentulous patients (Figure 50-26), this limitation has prompted a number of modifications or adjunctive procedures that are designed to optimize the fibula as a recipient site for implants. Most notably, these modifications include inseting the fibula closer to the superior border of the native mandible (Figure 50-27) or folding the flap on itself as a so-called “double barrel,” thus making the bone twice as thick. Distraction osteogenesis to increase the vertical height of the fibula has been reported and can be performed in a fashion similar to that of distraction osteogenesis of the vertically deficient alveolus.³⁰⁵⁻³¹⁰ Typically, the fibular reconstruction is allowed to mature for approximately 6 months or more to diminish the residual edema of the soft tissue elements and to allow osteosynthesis at the interfaces of the fibula to native mandible. The fibular reconstruction must be stable enough to allow removal of the reconstruction



FIGURE 50-24 A 58-year-old patient following composite resection of floor of the mouth cancer and reconstruction with a fibular osteocutaneous free flap. A, Postoperative intraoral appearance; B, dental rehabilitation with a removable prosthesis.

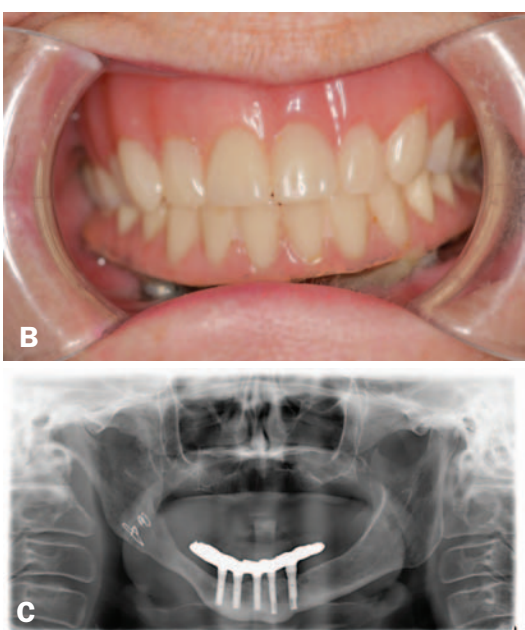


FIGURE 50-25 A 68-year-old patient 15 years following composite resection for floor of the mouth cancer and staged reconstruction using an iliac crest bone graft. A, Facial appearance; B, fixed removable prosthesis in place; C, panoramic radiograph.

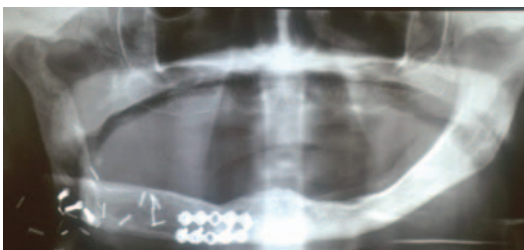


FIGURE 50-26 Panoramic radiograph of a 60-year-old edentulous patient following composite resection for mandibular alveolar ridge cancer and reconstruction with a fibular flap. Note that the height of the fibula approximates that of the native, atrophic, edentulous mandible.

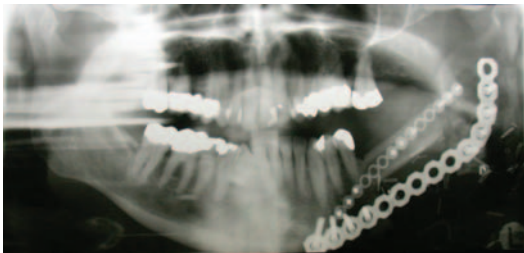


FIGURE 50-27 Panoramic radiograph illustrating the position of the fibula toward the superior border of the native mandible to facilitate implant-supported rehabilitation in this younger, dentate patient.

plate for access to create the osteotomies. The osteotomy of the fibula, application of the distractor, and an initial latency period of 5 to 7 days prior to distraction are similar to standard alveolar distraction (Figure 50-28). Dental implants can be placed after consolidation of the distraction regenerate has occurred. The skin paddle of the fibular flap used to cover the alveolar ridge often requires sacrifice and replacement with a split-thickness skin graft or palatal mucosal graft at the time of implant uncovering.

A wide range of reconstructive options for hard tissue, soft tissue, and composite defects are available. Depending on the particulars of the anatomy of the defect, planned outcome, patient’s tolerance for donor-site morbidity, and individual surgeon’s training and experience, several methods of reconstruction may be available. In general, the best option is the simplest one that will enable all of the functional and esthetic goals of reconstruction to be met. The oral and maxillofacial unit at Legacy Emanuel Hospital and Health Center has evolved to the point where the majority of patients with major ablative or post-traumatic defects of the head and neck are reconstructed with microvascular free flaps (Figure 50-29). The type of free flap used depends on the defect; however, the RFFF and fibula osteocutaneous flap have become the most frequent choices for almost all defects of the oropharyngeal region (Figure 50-30). A minority

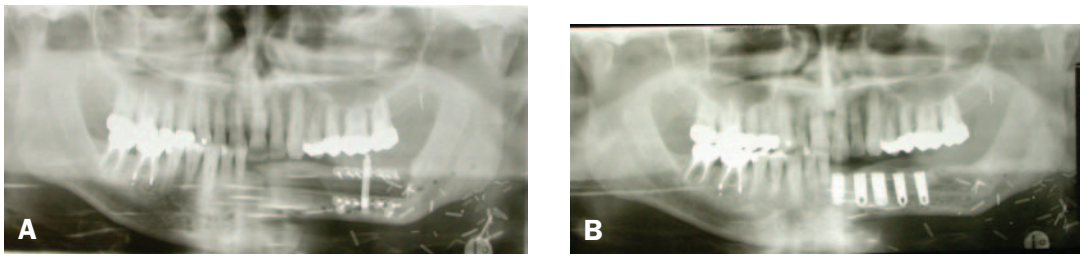


FIGURE 50-28 Vertical distraction osteogenesis of the fibula to augment the neomandible to facilitate implant-supported prosthetic rehabilitation. A, Panoramic radiograph following device activation; B, panoramic radiograph following implant placement into the distracted bony regenerate.

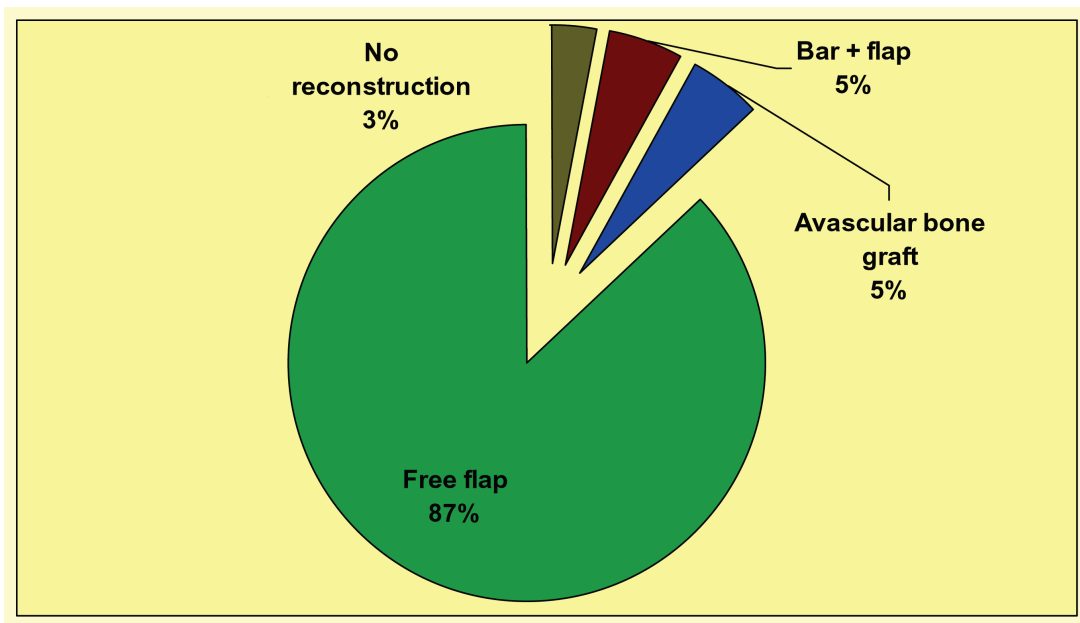


FIGURE 50-29 Patients undergoing mandibular reconstruction at Legacy Emanuel Hospital and Health Center, 2000–2005.

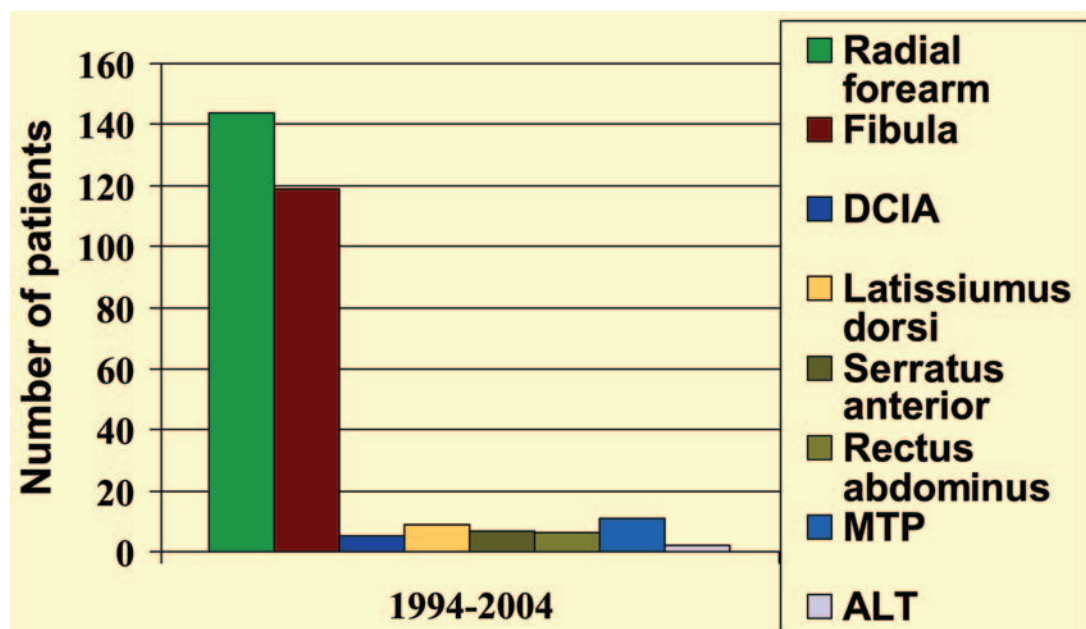


FIGURE 50-30 Types of microvascular free flaps used for immediate reconstruction of ablative defects at Legacy Emanuel Hospital and Health Center, 1994–2004.

of patients are managed with nonvascularized bone grafts and include those with short (< 6 cm) segmental mandibular defects in nonirradiated patients with adequate soft tissue and/or benign disease or post-traumatic deformities. Regional soft tissue flaps, such as the pectoralis major myocutaneous flap, are used much less frequently than in years passed and are generally reserved for salvage or palliative procedures.

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Bone Grafting in Orthognathic Surgery

Harry C. Schwartz

The successful correction of dentofacial deformities using conventional osteotomies is, in part, dependent on effective stabilization and rapid healing of the repositioned bony segments. When there are broad areas of contact along the bone cuts, firm bony union can be anticipated. In the case of segmental osteotomies or osteotomies in which anterior, posterior, lateral, rotational, or other more complex three-dimensional movements take place, there can be fewer areas of contact along the bone cuts. This can lead to instability, delayed union, fibrous union, or relapse. Bone grafting has been shown to improve mechanical stability and to hasten bony union. The graft is a physical barrier that prevents the ingrowth of fibrous tissue. It provides a physiologic matrix that is resorbed and replaced by viable new bone. Although some workers recommend the use of banked bone, bone substitutes, or products containing bone morphogenetic protein (BMP), autogenous bone offers many advantages. It does not elicit an immune response. It contains native BMP. Some living cells survive transplantation and contribute to osteogenesis. Although there are advocates of autogenous iliac crest or cranial bone grafts, abundant bone is available locally during the course of orthognathic surgery. It is rarely necessary to obtain bone grafts from distant sites.

Indications

Bone grafting is very useful in segmental osteotomies. The periodontal ligament is the interface between the teeth and the underlying bone segments. There can be considerable motion across the periodontal ligament, especially during orthodontic treatment. Wiring the teeth into a splint may not precisely position the bony segments. This can be demonstrated when you compare the osteotomy gap produced in model surgery (Figure 51-1) with the smaller gap produced during the actual surgery (Figure 51-2). If ignored, this discrepancy can lead to relapse when the splint is removed. A properly shaped bone graft maintains the correct orientation of the bony segments and facilitates osteogenesis in the osteotomy gap (Figure 51-3).

Bone grafting is also useful in situations in which there is little contact between bone



FIGURE 51-1 Note the size and angulation of the interdentary osteotomy following model surgery for correction of a dual-plane occlusion in the maxilla.



FIGURE 51-2 The size and angulation of the osteotomy are consistently smaller during the actual surgery. This is due to inherent mobility in the periodontal ligaments of the teeth that have been wired into the occlusal splint.



FIGURE 51-3 A wedge-shaped bone graft restores the osteotomy to its planned dimensions. Stress is removed from the periodontal ligaments, eliminating an important factor in early relapse.

segments. There are many examples in the maxilla: osteotomies for advancement (Figure 51-4), vertical lengthening (Figure 51-5), or other complex movements. In the mandible, there are various ramus osteotomies (Figure 51-6), the vertical midline osteotomy for arch narrowing (Figure 51-7), and asymmetric (Figure 51-8) or lengthening genioplasty (Figure 51-9).

Bone grafts help maintain the three-dimensional orientation of the osteotomy segments. They prevent fibrous tissue ingrowth that could lead to fibrous union. They stimulate osteogenesis, resulting in rapid bony healing. This increases stability and diminishes relapse. Although there are authors who cite a low incidence of instability if rigid internal fixation is used without bone grafting, it is difficult to accept even a small number of problems when grafts are so readily available.

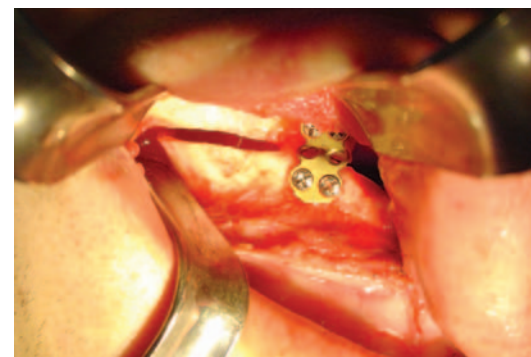


FIGURE 51-4 A large gap is present in the buttress and anterior maxillary wall after a 6 mm maxillary advancement. This gap should be grafted.

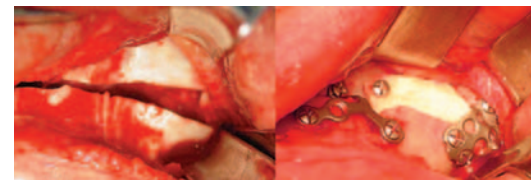


FIGURE 51-5 The left posterior maxilla has been lengthened by 7 mm to correct an occlusal cant (*left*). The large gap has been closed with a bone graft that is wedged beneath the fixation plates and attached by a screw to the anterior maxillary wall (*right*).

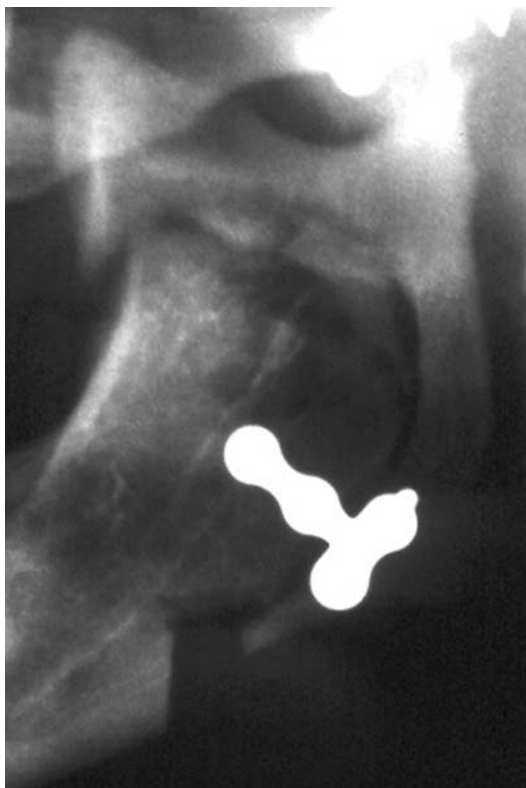


FIGURE 51-6 Bone graft is placed in the superior gap following a C osteotomy of the mandible.

Preoperative Case Planning

A major advantage of the use of local bone grafts is that they require little planning beyond standard orthognathic case preparation. If large movements are necessary, the need for larger volumes of bone should be anticipated. Appropriate grafts are then obtained so that they will be available when rigid fixation is placed. Examples of such movements include large maxillary advancements in cleft palate or obstructive sleep apnea patients and vertical maxillary lengthening in patients with alveolar hypoplasia or canted occlusal planes.

Donor Sites

Bone is routinely removed during the course of orthognathic procedures. If this bone is purposely excised in intact segments (rather than being ground away with burs or rasps), it will be available for grafting.

The sagittal mandibular ramus osteotomy provides several potential donor sites:

- The anterior portion of the proximal segment and the external oblique ridge are often trimmed during a sagittal mandibular setback (Figure 51-10). These can provide excellent grafts of solid cortical bone. The anterior area is especially useful since a precise fit is not necessary in this area for healing of the osteotomy.

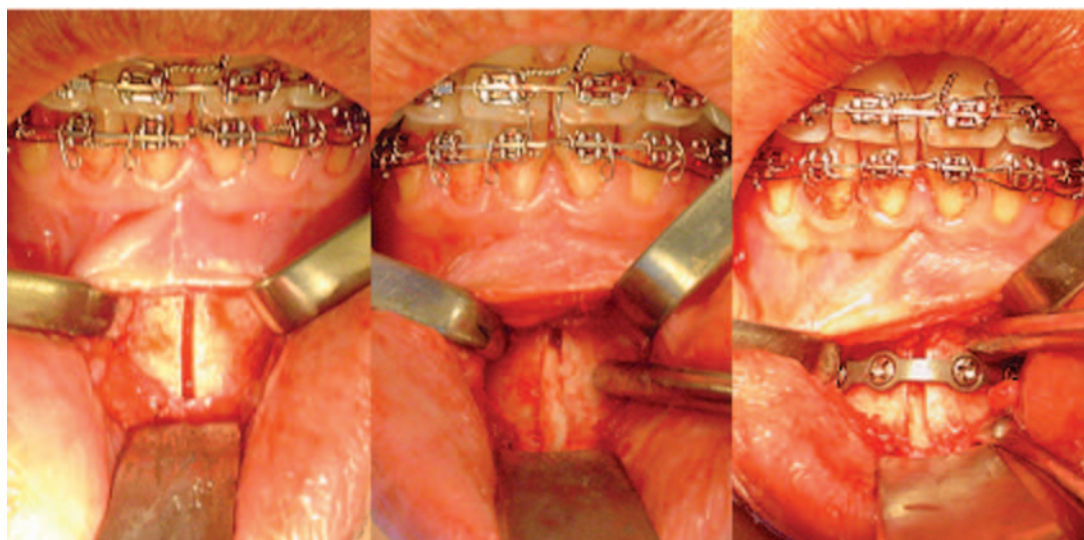


FIGURE 51-7 Sagittal mandibular osteotomy with midline osteotomy for arch narrowing has been completed (left). A graft is placed to stabilize the midline gap (center) before rigid fixation is placed (right).

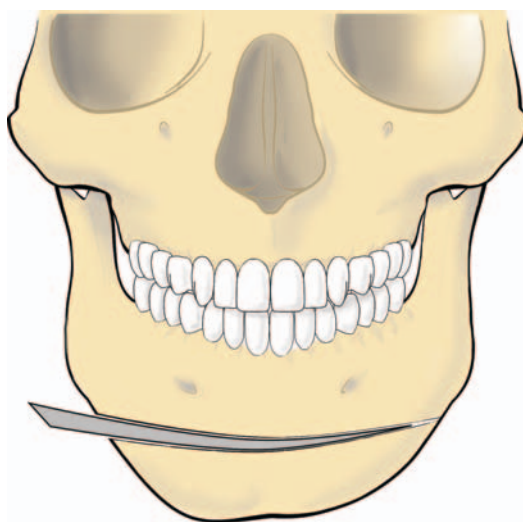


FIGURE 51-8 In asymmetric genioplasty, bone can be removed from the long side to be used as a graft elsewhere. Other cases may require grafting to lengthen the short side.

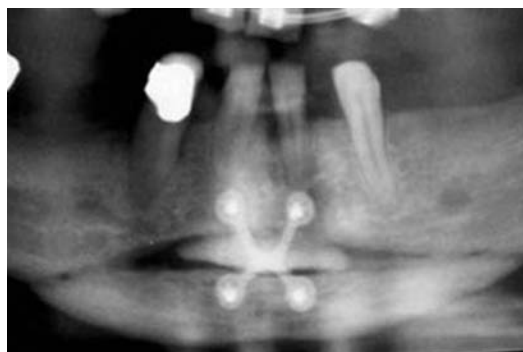


FIGURE 51-9 Bone grafting stabilizes the gap created in a vertical lengthening genioplasty.

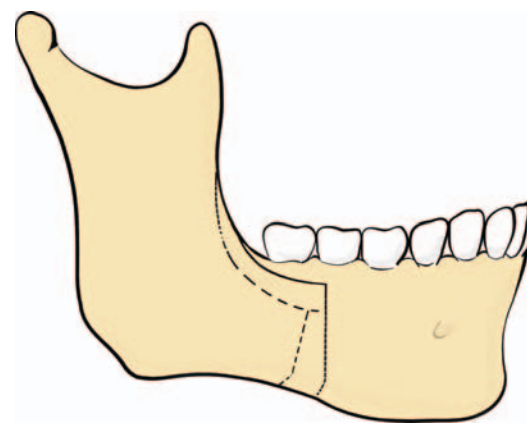


FIGURE 51-10 In a sagittal mandibular setback, bone is removed from the anterior portion of the proximal segment and from the external oblique ridge (dashed lines). This prevents overlap along the anterior osteotomy and impingement on the second molar after the teeth are repositioned. These are two excellent sources for bone grafts.

- The sagittal osteotomy can be lengthened anteriorly almost to the mental foramen if a larger graft is necessary (Figure 51-11). A sufficient area of bone remains in contact posteriorly to allow for healing of the osteotomy. Bone can be removed from this area during a mandibular advancement as well.
- The internal oblique ridge is often reduced with a large bur to visualize the lingula prior to making the medial osteotomy. This bone can be excised, providing a wedge of cortical bone (Figure 51-12).
- The bone superior to the medial osteotomy must be reduced if there has been a simultaneous maxillary impaction. This triangular area is bounded inferiorly by the bone cut, posteriorly by the sigmoid notch, and anteriorly by the anterior border of the

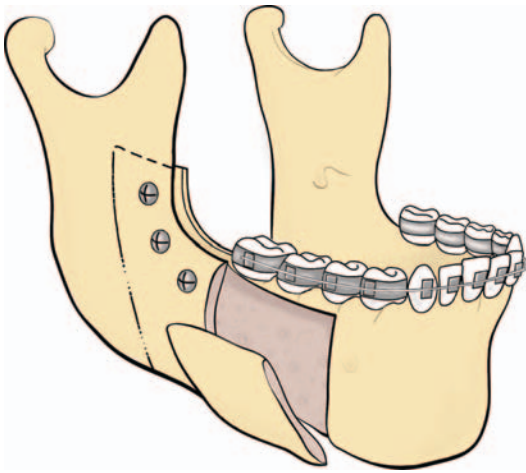


FIGURE 51-11 The sagittal osteotomy can be lengthened anteriorly almost to the mental foramen if a larger bone graft is needed. Sufficient bone remains posteriorly for fixation and healing of the osteotomy.

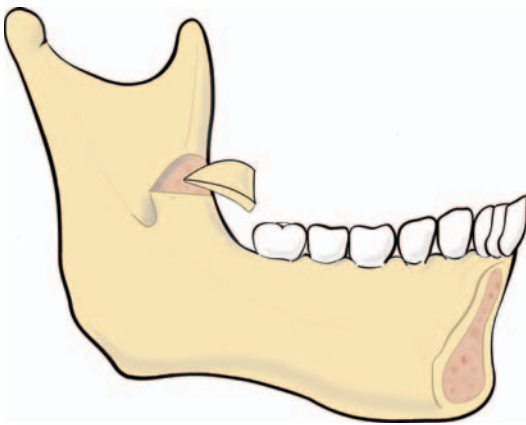


FIGURE 51-12 Instead of burring the medial cortex to visualize the lingula, this area can be removed to form a small bone graft.

ramus. It can be excised up to the coronoid process, producing another cortical bone graft (Figure 51-13). The region plays no part in healing of the osteotomy.

- The inferior portion of the sagittal osteotomy often follows the mylohyoid line. This leaves the entire lower border and up to a centimeter of the lingual cortex attached to the proximal segment (Figure 51-14). It can provide a long, narrow graft of cortical bone. This bone is not necessary for healing of the osteotomy.

The Le Fort I maxillary osteotomy also provides potential donor sites:

- The maxillary walls must be reduced during superior maxillary repositioning. These areas can be excised, providing thin, narrow cortical bone grafts (Figure 51-15).
- The inferior nasal aperture must also be reduced during superior maxillary repositioning to prevent buckling of the anterior

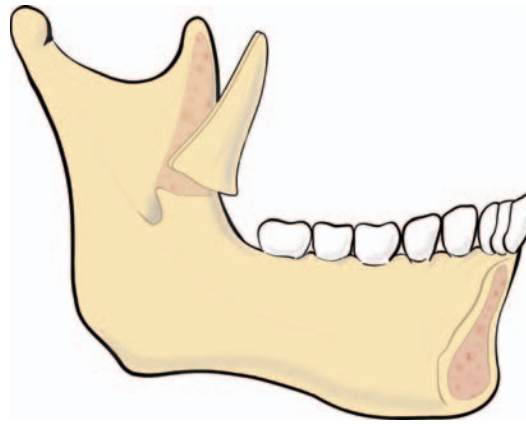


FIGURE 51-13 The area of the distal segment superior to the medial osteotomy must be reduced in a posterior impaction. The entire triangular area between the medial osteotomy and the coronoid process can be removed to form a bone graft.

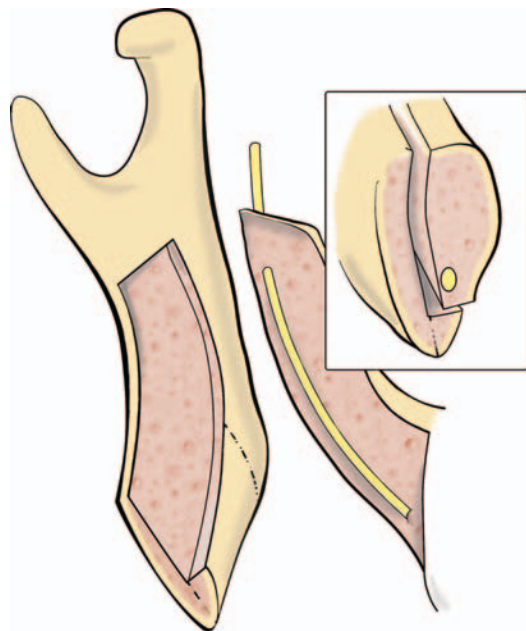


FIGURE 51-14 The inferior portion of the lingual cortex often remains with the proximal segment during a sagittal mandibular osteotomy. This can be removed to form a long, narrow bone graft.

nasal septum. This area can be excised to provide a chevron-shaped cortical bone graft (Figure 51-16).

- The lateral nasal walls and nasal septum are removed after downfracture in almost all cases to prevent them from lacerating the nasal mucosa. They provide thin cortical bone grafts.
- The maxillary crest must be reduced in many cases to prevent it from buckling the nasal septum. The midline of the hard palate is often quite thick. The crest can then be excised to form a long, diamond-shaped graft (Figure 51-17). If the hard palate is thin, the crest is excised as a long triangular graft.

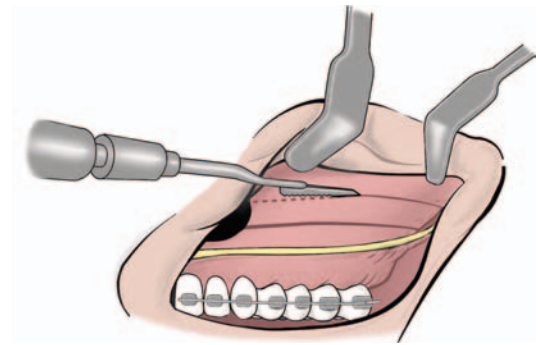


FIGURE 51-15 Bone graft is removed from the maxillary walls during superior maxillary repositioning.

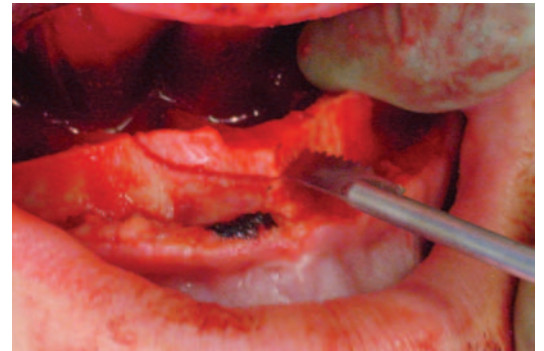


FIGURE 51-16 Bone graft is removed from the floor of the nasal aperture during superior maxillary repositioning.

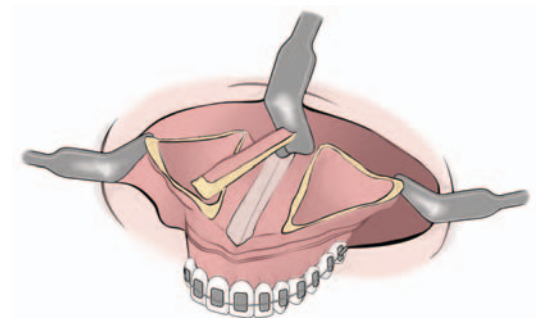


FIGURE 51-17 Bone graft is removed from the maxillary crest to prevent it from buckling the nasal septum after superior maxillary repositioning.

The mandible is an excellent donor site, even if a sagittal osteotomy is not to be performed:

- The lateral cortex of the mandible can be removed as a long rectangle of cortical bone that extends from the retromolar area to the mental foramen and from the external oblique ridge to the lower border (Figure 51-18). Bilateral grafts can be taken.
- The external oblique ridge and anterior border of the mandible can be excised from the molar area up to the coronoid process as a long, curved rectangle of cortical bone (Figure 51-19). Bilateral grafts can be taken.
- A cortical window can be excised from the mandibular symphysis between the roots of

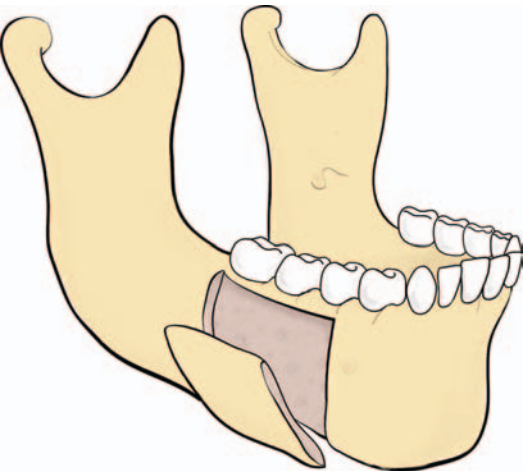


FIGURE 51-18 Even if a mandibular osteotomy is not needed, the lateral cortex of the ramus is an excellent source for a bone graft. In effect, the surgeon purposely creates a “bad split.”

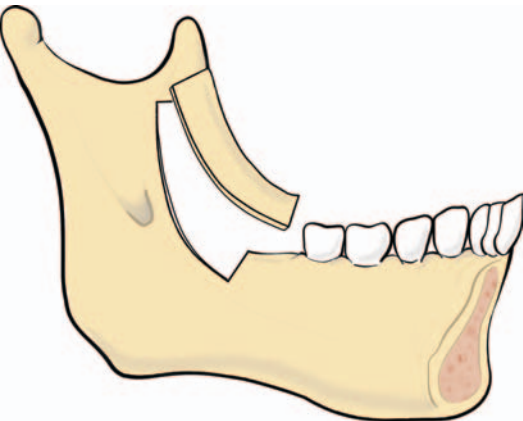


FIGURE 51-19 Even if a mandibular osteotomy is not needed, the anterior border of the ramus and external oblique ridge is an excellent source for a bone graft.

the canines and the lower border (Figure 51-20). If necessary, cancellous bone can also be removed from this window and used for grafting.

- A corticocancellous bone graft can be excised from the symphysis of the mandible during a vertical reduction genioplasty (Figure 51-21).

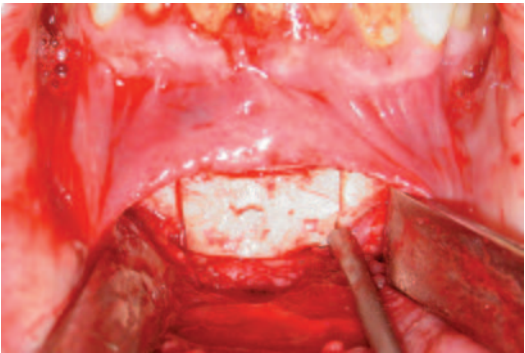


FIGURE 51-20 A window is made in the anterior cortex of the mandible at the symphysis. This is an excellent source for both cortical and cancellous bone grafts.

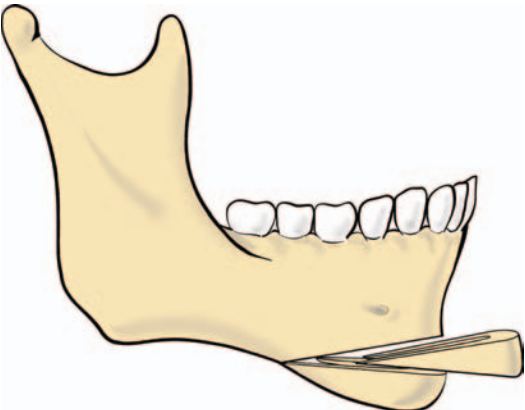


FIGURE 51-21 The wedge of bone removed from the mandible during a vertical reduction genioplasty is another source for a bone graft.

Autogenous bone grafting from local donor sites has proven to be technically simple and extremely versatile during orthognathic surgery. It results in greater stability and more rapid bony healing. There is a single operative field, with no worry about donor-site contamination. Postoperative care is the same as for the underlying orthognathic procedure. There is no increase in complications.

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Genioplasty with Implants

Kevin L. McBride

History

The anterior mandibular sliding osteotomy technique permits correction of almost all cosmetic problems. However, it has some limitations and is a more complex procedure than implant placement. The osteotomy technique requires expensive instrumentation, plates and screws, more training and technical expertise, and more surgical time than do the implant techniques. Because materials have improved, and better implant designs have become available, surgeons have returned to implant techniques. Today, the availability of a wide variety of implant materials of different shapes and sizes permits correction of most problems with the same basic technique.

Early chin implants frequently provided compromised esthetic results. Occasionally, the outline of the implant could be seen, because it tented up the skin, and the edges of the implant were not smoothly tapered to blend into the surrounding bone. The implants had a tendency to move from the desired position because of muscle contraction or external pressure. These problems were due to the shape of the chin implants, which were generally small, oval, “button”-shaped wafers that covered just the anterior component of the chin. If the pocket created for the implant had exactly the right position and dimensions, then the implant tended to stay in place relatively well. However, the activity of overlying muscles could move the implant. If the pocket was too large or not positioned ideally, then the implant could move within the pocket in the immediate postoperative period. Chin implants are now available in various solid and porous, highly biocompatible materials.¹ It was felt that tissue growth into the porous implants would reduce displacement. However, tissue ingrowth requires several weeks or months, during which movement can occur. Therefore, good initial stabilization is desirable, even when porous implants are used.

The “button” style implants were prone to produce erosion of the anterior cortex of the mandible under the implant, permitting it to move posteriorly.² The factors responsible for bone resorption under silicone implants are not well understood. The newer implants that extend

along the lateral aspect of the mandibular body, and increase the surface area of the implant against the bone, seem to cause substantially less bone resorption.

Good implant stabilization at surgery is provided by controlling the pocket size, using both implants with long lateral extensions and screw fixation. Most of the currently available chin implants extend posteriorly along the lateral body of the mandible into the first molar region. These long extensions help to stabilize the implant in two dimensions. In addition, a screw is frequently used to secure the implant to the mandible in the midline. This provides excellent vertical and additional lateral stabilization of the implant. Implants that are not stabilized with screws have a tendency to be displaced vertically by mentalis muscle function, which lifts the chin prominence to a higher level than is esthetically ideal. The screw controls the vertical position of the implant so that the chin projection point is maintained at the optimal level.

Advantages of Implants

Implants have several advantages over sliding osteotomies for most chin augmentation procedures (Table 52-1). Chin width problems are more easily corrected with implants than with osteotomies. The width and shape of the chin can be modified by simply selecting a square-shaped implant or a tapered implant, or by carving the lateral margins or front of an implant. Sliding osteotomies with large advancements tend to develop a ledge above the advanced segment. This ledge may contribute to the development of an

overly deep labiomental fold. It is frequently necessary to fill the defect above the advanced bony segment with a bone graft, or an alloplastic material, to create a better contour by preventing the soft tissue from collapsing into the defect. This correction has been built into the shape of some chin implants. These implants have a vertical extension that fills the potential contour deficiency above the chin prominence and reduces the ultimate depth of the labiomental fold.

Limitations of Implants

There are notable limitations to what can be achieved with chin implants. Owing to lack of stretching of the suprahyoid muscles, there is less improvement in the submental neck contour. In patients who would benefit from improved cervical contours, neck liposuction and platysma muscle tightening should be considered. These procedures may also be useful when a sliding osteotomy is performed.

There is virtually no capacity to vertically lengthen or shorten the chin with an implant alone. However, the chin can be shortened with an inferior border osteotomy, and a chin implant can be placed to provide the desired projection and lateral augmentation. Similarly, vertical lengthening of the chin may be accomplished with a horizontal osteotomy of the anterior mandible. The bony segment can be inferiorly repositioned, but not advanced, and stabilized with plates and screws. An implant can be placed over the bony segment and the vertical bony defect, to provide the desired projection and lateral contour augmentation. This is particularly

Table 52-1 Advantages of Chin Implants Compared with Osteotomies	
1.	Shorter, simpler procedure with faster recovery
2.	Implants may be carved to create custom contour
3.	Less bruising and swelling due to lack of bone cut
4.	Implant sizes permit more accurate visualization of the anticipated result
5.	May be accomplished through a submental incision used for cervical liposuction
6.	No need for expensive saw
7.	Lower cost of components (implant and screw versus bone plate and multiple screws)
8.	May be placed simultaneously with mandibular subapical osteotomy
9.	Technique more easily mastered than osteotomy

appropriate in situations where attempting to produce the desired lengthening, and advancement with the bony segment alone would make it difficult to stabilize the segment or would not provide the desired esthetic result. By using an implant to provide the desired projection augmentation, the mobilized inferior border segment can be maintained, with better bony contact and stability.

Preparing for Implant Placement

The surgeon should become familiar with the design differences of the various implants that are currently available. It may be helpful to have multiple sizes of two or three different implant styles available for any given case. It is helpful to have implant sizers available for each design (Figure 52-1). The implant sizers are made of colored, opaque silicone. Silicone implants for permanent placement are clear and colorless (Figure 52-2). Porous implants are usually white. Generally, the preoperative assessment will permit selection of the best implant form for any patient. However, anatomic factors not recognized preoperatively may dictate the choice of a different implant shape than that originally planned, or the need to shape the implant by carving it with a scalpel.

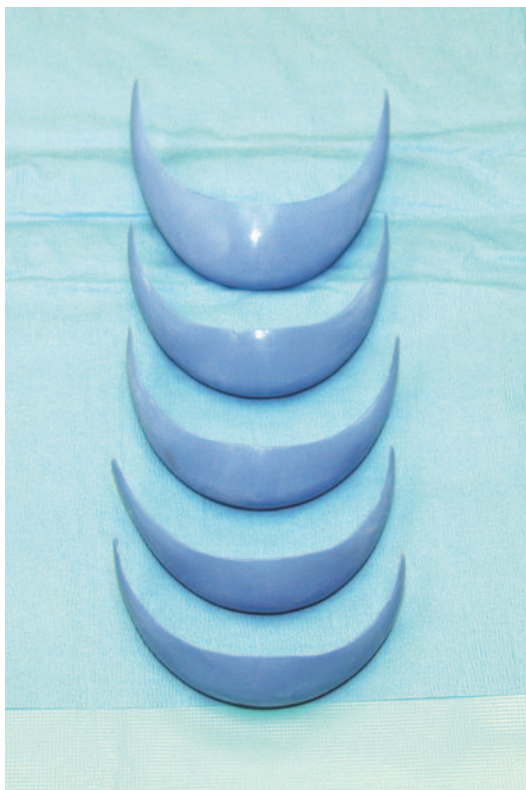


FIGURE 52-1 A series of five blue sizers for Flowers Mandibular Glove implants (Implantech Associates Inc, Ventura, CA). The sizers are placed in the surgical pocket to determine the size and shape that will provide the best esthetic results. The sizers are not for permanent implantation.

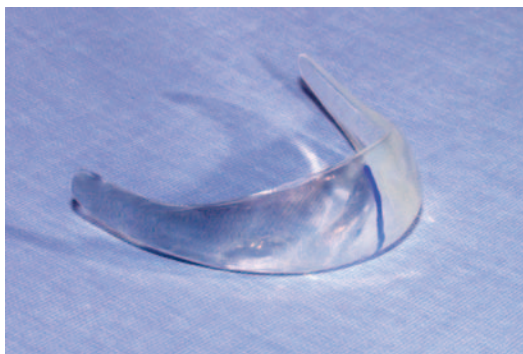


FIGURE 52-2 A clear, medium, silicone chin implant intended for permanent implantation.

Surgical Technique for Chin Implant Placement

Chin implants can be placed with the patient under local anesthesia, intravenous sedation, or general anesthesia, based on the preferences of the patient and the surgeon. In order to provide satisfactory patient comfort in the immediate postoperative period, anesthesia of the cervical nerve and the buccal and inferior alveolar branches of the second division of the trigeminal nerve must be provided. The local anesthetic solution should also be injected directly into the chin soft tissue to provide improved hemostasis. A long-acting anesthetic, such as Marcaine with epinephrine, provides vasoconstriction and several hours of analgesia postoperatively. Sedation or general anesthesia is desirable for patient acceptance, and can be helpful in reducing the intraoperative blood pressure, thereby reducing blood loss and improving visibility at the site.

The face and chin are prepared with an antimicrobial solution, and the face is outlined with sterile towels. Preoperative or intraoperative and short-term postoperative antibiotic therapies may be employed to reduce the potential for infection when the procedure is performed intraorally. If the implant is placed through a submental incision, then antibiotic therapy may not be appropriate.³

Intraoral Approach

The incision in the anterior mandibular vestibule is placed in an identical position to that used for osteotomy advancements (Figure 52-3). The length of the incision may be reduced to approximately 3 cm, because the access required to place the implant is less than that needed to perform an osteotomy. Care is taken to insure that the incision is far enough anteriorly for a substantial pedicle of mentalis muscle to be left attached to the anterior mandible above the incision. This is critical in order to prevent dehiscence of the suture line and ptosis of the lower lip.

The dissection is carried down through the periosteum, using an electrosurgical cutting cautery. The periosteum is elevated down to the inferior border of the mandible. A subperiosteal tunnel is extended posteriorly along the lateral body of the mandible, below the mental nerve on each side to at least the first molar region, to accommodate the posterior extensions of the implant. A slim channel retractor, such as an Aufricht retractor, may help with visualization and protection of the mental nerve as it exits the lateral border of the mandible. Considerable care should be taken to prevent direct trauma to the mental nerve during the dissection and implant placement.

It is very important to cut the periosteum along the inferior border of the mandible for at least 2 cm on either side of the midline. The soft tissue should be stretched to separate the edges of the periosteum by several millimeters. This produces a pocket in the soft tissue to accommodate the bulk of the implant. If the periosteum is not incised, then the overlying soft tissue will not be long enough to wrap around the implant, making it difficult to close the incision without tension and contributing to ptosis of the lower lip. In addition, the normal contour of the chin may be altered, and unnatural soft tissue fullness may develop below the inferior border of the implant.

After the pocket has been developed, the implant sizers for the implant style that is expected to produce the best result are placed sequentially until the desired projection and lateral contour are obtained. Sizers for other implant styles may be tried in place, to find the implant size and form that provide the best result. If there is conflict between the desired transverse width of the implant and the desired projection, then it is generally best to select the larger implant size. The excess projection, or excess width, can then be reduced by carving the implant with a scalpel. The implant can be made more square at the tip by removing a portion of the tip of the implant, and the transverse width can be reduced by narrowing the lateral extensions of the implant. The vertical height can be reduced where necessary, to obtain the desired contour. Chin asymmetries can be corrected by moving the implant midline to the weak side of the chin, or by carving the implant to compensate for the bony asymmetry.

After any necessary carving, the implant is thoroughly washed and inserted into the subperiosteal soft tissue pocket. The implant midline, which is marked by the manufacturer, is positioned over the anterior mandibular midline. Typically, there is a bony prominence at the mandibular midline that can be used to position the implant midline properly, or the midline between the mandibular central incisors may be used as a reference. The vertical position of the

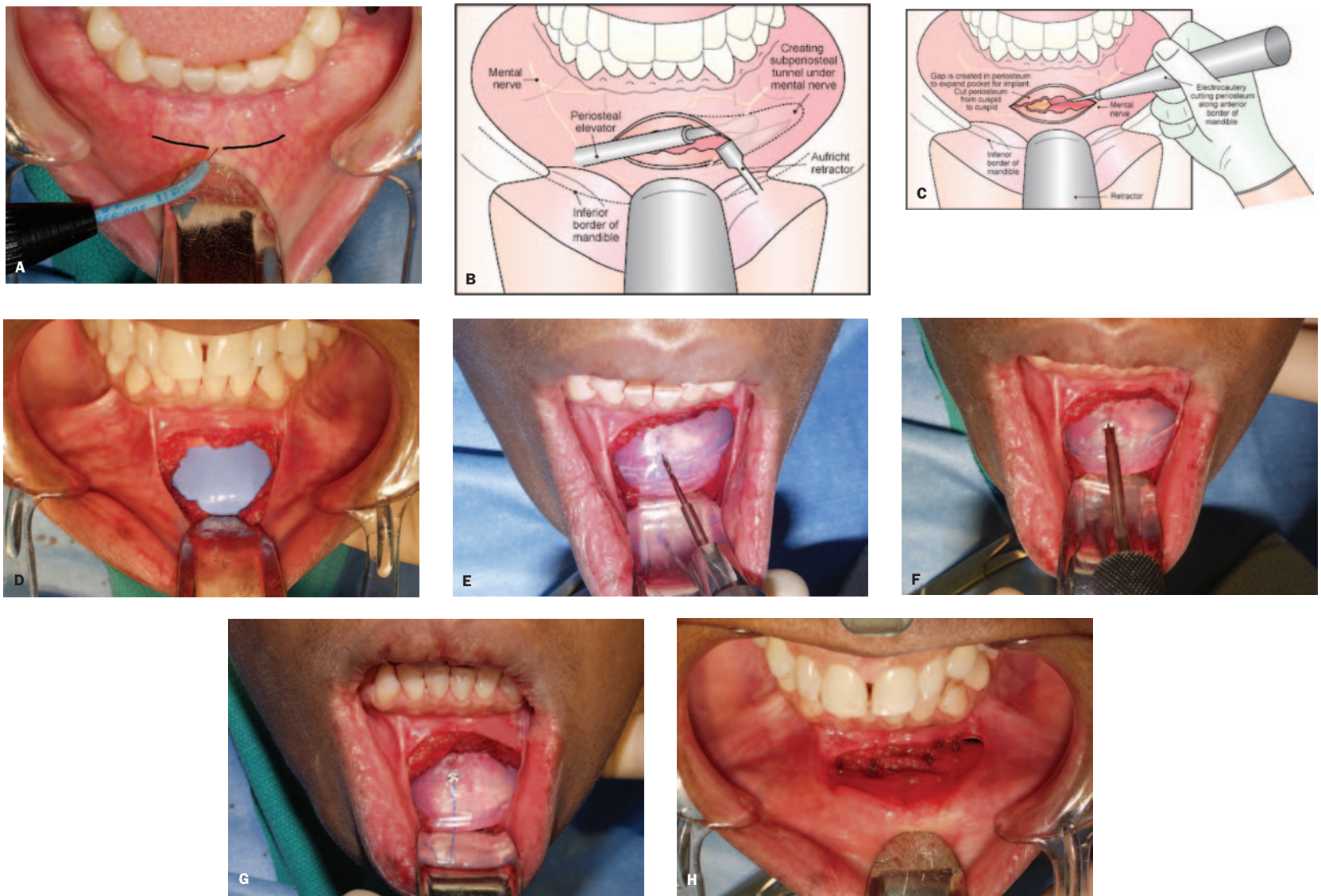


FIGURE 52-3 Intraoral surgical technique illustrations. *A*, The incision is made at least 10 to 15 mm from teeth to leave a strong mentalis muscle attachment on the mandible. *B*, A subperiosteal tunnel is dissected posteriorly under the mental nerve to the first molar area bilaterally. *C*, The periosteum is cut along the inferior border of the mandible for 3 cm on either side of the midline. The tissue is stretched to create a gap in the periosteum. This expands the pocket for the implant so that the lip is not inferiorly displaced. *D*, Implant sizers are test-fitted until the desired size and shape are selected. An extra-large sizer is in the pocket. *E*, The selected implant is placed in the pocket and positioned in the midline along the inferior border of the mandible. A hole is drilled through the implant and a few millimeters into the bone. *F*, A screw is passed through the implant and into the bone to provide fixation. *G*, The stabilizing screw is flush with the anterior surface of the implant. *H*, The muscle layer is closed meticulously with 3-0 chromic sutures. The mucosa is then closed as a separate layer.

implant is typically adjusted so that the inferior border of the implant blends imperceptibly with the inferior border of the mandible. The implant is held in position, and a hole is drilled through the implant and through the anterior cortex of the mandible in the midline. A screw of diameter 1.6 to 2.0 mm is passed through the implant and into the hole in the cortex. The screw is tightened sufficiently so that the head is flush with the implant surface. The surgical site is thoroughly irrigated, and the incision is closed in two layers. The muscle layer is closed meticulously with interrupted 3-0 vicryl or chromic sutures. The mucosa is closed with running 3-0 chromic or similar sutures.

A small pressure dressing can be applied, using elastic tape or an elastic headband designed

for that purpose. If employed, the pressure bandage may be left in place for 2 to 3 days.

Submental Approach

With the submental approach, the same facial preparation and draping are accomplished as for the intraoral approach. The same local anesthetic injections are performed and an additional injection is administered behind the submental crease. A 2.5- to 3-cm-long transverse incision is made approximately 2 to 3 mm behind the submental crease (Figure 52-4). The dissection is carried down to the inferior border of the mandible, where the periosteum is incised. The periosteum is reflected superiorly, just enough to provide the desired pocket height for the implant. A

subperiosteal tunnel is dissected along the lateral aspect of the mandible at the inferior border below the mental nerve to the first molar region bilaterally. Care is taken to avoid direct trauma to the mental nerve. An Aufricht retractor is helpful, to permit visualization and protection of the nerve during the dissection. Once the desired pocket size has been developed, the implant sizers are tried in place until the implant size that produces the desired contour is identified. If a large implant is needed, it may be helpful to horizontally incise the periosteum at the superior margin of the pocket, and stretch the tissue apart along the incision, to increase the pocket size. Otherwise, it may be difficult to close the incision, and the inferior border soft tissue may be distorted.

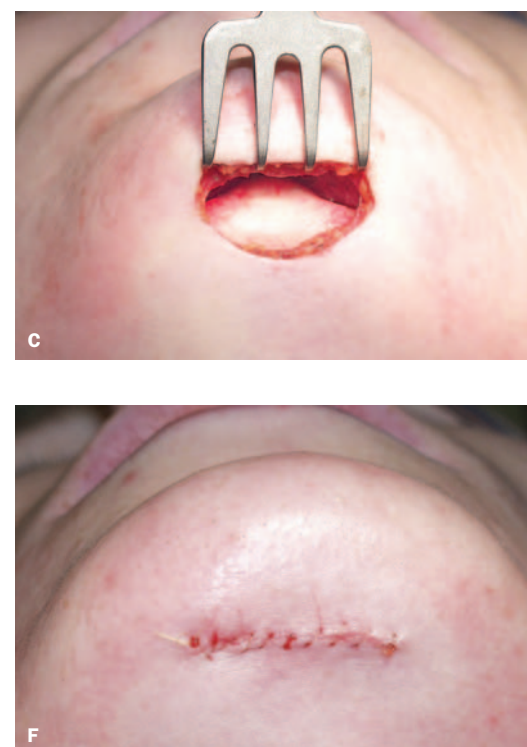
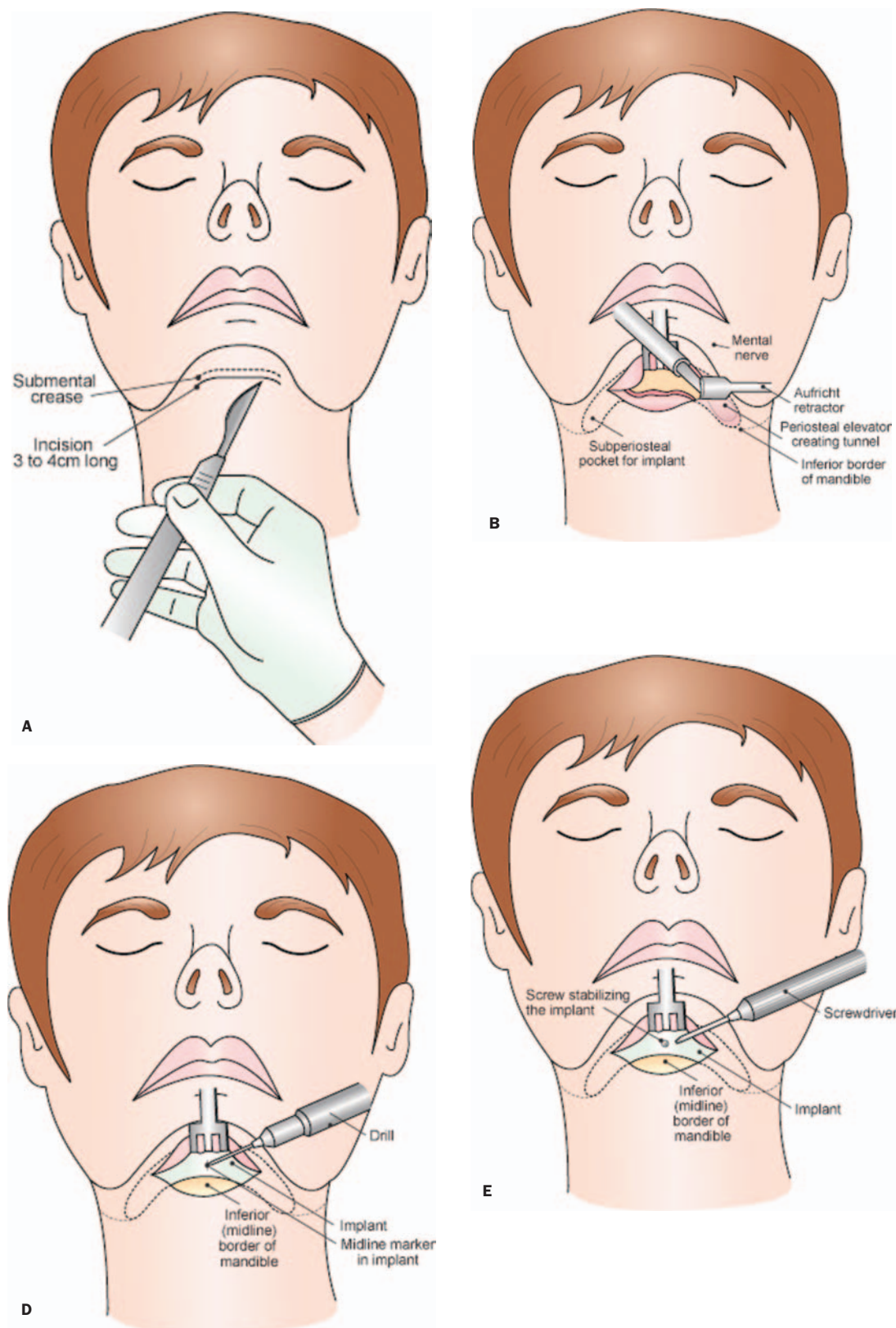


FIGURE 52-4 Extraoral surgical technique illustrations. A, A 3 cm incision is made a few millimeters behind the submental crease, and a blunt and sharp dissection is extended through the periosteum at the inferior border of the mandible. B, Subperiosteal tunnels are developed bilaterally along the inferior border of the mandible, under the mental nerve, to the first molar region. An Aufricht or similar retractor aids in visualizing and protecting the mental nerve. The periosteum is elevated up the anterior bony surface for about 15 mm, or to the height of the proposed implant. There is usually a triangular prominence of bone in the midline that is used as a reference for positioning the implant. C, A shallow hole is drilled in the inferior border to mark the midline. The selected implant is placed in the pocket and positioned in the midline along the inferior border of the mandible. D, A hole is drilled through the implant and a few millimeters into the bone. E, A screw is passed through the implant and into the bone to provide fixation. F, The skin is closed after the muscle-subcutaneous layer has been closed as a separate layer.

The sterile implant package is opened, the implant is washed with sterile saline, and the implant is slipped into the pocket. The midline marker is aligned with the mandibular midline, and the inferior border of the implant is aligned with the bony inferior border. Chin asymmetries can be corrected by moving the implant midline to the weak side of the chin, or by

carving the implant to compensate for the bony asymmetry. A hole is drilled through the implant and through the anterior cortex of the mandible in the midline. A screw of diameter 1.6 to 2.0 mm is used to secure the implant to the mandible. The site is irrigated and the wound is closed in layers with 3-0 vicryl or chromic gut sutures. The skin is closed with 5-0 nylon or similar

sutures. An elastic pressure bandage may be applied.

Postoperative Care

Postoperative care is identical to that provided for sliding osteotomies. In general, there is less swelling, bruising, and discomfort associated with

implant placement compared with sliding osteotomies. Consequently, the patient's "down time" is reduced, and the lower lip function and overall chin contour may return to normal more rapidly. Photographs taken before and after augmentation genioplasty demonstrate the long-term improvement that can be achieved (Figures 52-5 and 52-6).



FIGURE 52-5 A, Preoperative lateral view, with deficient chin projection and poor definition of the mandibular border. B, Postoperative lateral view, with improved neck contour and chin projection, following silicone implant and neck liposuction.



FIGURE 52-6 A, Preoperative frontal view, with cervical lipomatosis and a tapered chin that does not have the masculine strength that the patient desired. B, Postoperative frontal view, with a wider and stronger chin contour and improved neck contour, after chin implant and cervical liposuction. C, Preoperative lateral view, with deficient chin projection and poor mandibular border definition. D, Postoperative lateral view, with improved chin projection and neck contour.

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Faciocraniosynostosis Surgical Treatment Strategy in One or Two Stages: Le Fort III and Frontofacial Monobloc Advancements

Eric Arnaud, Daniel Marchac and Dominique Renier

Surgical treatment of faciocraniosynostosis involves complex techniques, which must address two issues¹⁻³:

- Prevention of cerebral damage secondary to the craniosynostosis: The synostoses may cause skull constriction, which could lead to increased intracranial pressure (most commonly in bicoronal or multiple synostoses).
- Optimal morphologic correction of the facial retrusion and its consequences: exorbitism (which threatens vision when severe) and upper airways impairment (which may cause chronic hypoxemia).

The traditional strategy of surgical treatment has been a two-stage strategy to diminish the risks (Figure 53-1)²⁻⁴:

1. The conventional approach to the cranium involves augmentation of its volume with a fronto-orbital advancement, best performed

before 1 year of age (see Figure 53-1A). This cranio-orbital intervention corrects the problems associated with craniosynostosis in a single procedure in the vast majority of cases.^{5,6} Cerebral growth is almost complete by 3 years of age, and the risks to the brain are minimal after this time. The remaining cerebral risks are limited unless a late-appearing multiple synostosis may develop.

2. For those in whom there is an associated facial retrusion, correction is performed at a variable age depending on the severity of the deformity and its esthetic and functional consequences. Facial growth is complete at around 16 to 18 years, and operative treatment is therefore performed at this age to correct facial malformations definitively in one procedure. In this instance, a definitive Le Fort III osteotomy performed late would not require distraction (see Figure 53-1B).

Although this strategy is applicable for minimal deformities, it is not possible to delay facial correction in those children who display more severe malformation (Figure 53-2, A to C) without the risk of major psychological sequelae. In such cases, it is possible to operate sooner, accepting that since the genetic growth disturbance will remain (Figure 53-2D), further surgery will be required in due course. Generally, the magnitude of the requisite interventions decreases as the years pass.

Hypoxemia and sleep apneas are also an indication to perform a facial advancement whenever diagnosed and, therefore, could achieve the removal of a tracheostomy or its avoidance. Now that we routinely screen our faciocraniosynostotic patients for respiratory disturbances, the frequency of such impairments is found to be higher than what was previously estimated.⁷

In the absence of important respiratory problem or severe morphologic impairment, the facial advancement should be delayed²: the older the child, the more definitive the dentition is, and the more stable will be the occlusion. The best occlusion is a warrant for stability (Figure 53-3) and a good morphologic outcome; nevertheless, in an adult patient, it is not always possible with a single Le Fort III advancement to obtain such a satisfactory occlusion. Owing to the variation of the phenotype in a faciocraniosynostotic patient, the retrusions at the orbital and occlusal levels may be variable, and priority should be given to the orbital morphology. In an adult patient, an additive procedure such as a Le Fort I, delayed or in combination with the Le Fort III, can solve the problem of the occlusion.

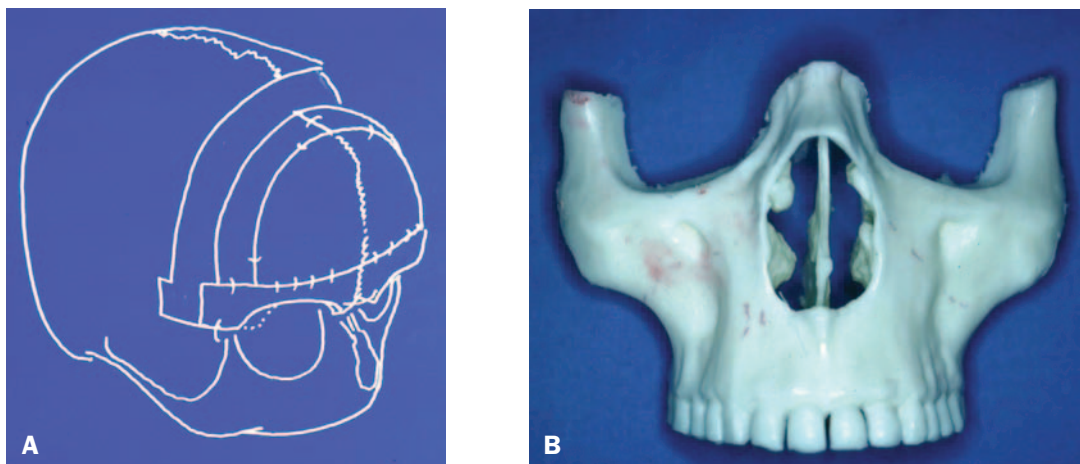


FIGURE 53-1 A, Fronto-orbital advancement. B, Facial advancement (Le Fort type III or Tessier osteotomy).



FIGURE 53-2 Example of a two-stage strategy for faciocraniosynostosis. A, Patient with unoperated Crouzon's disease with bilateral coronal synostosis. B, After fronto-orbital advancement (sleep apnea syndrome untreated). C, After conventional Le Fort III at age 6 years. D, At 11 years of age (observe the recurrence of facial imbalance because of a genetic lack of growth).

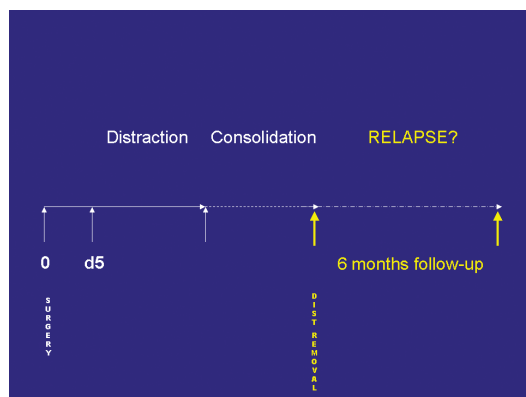


FIGURE 53-3 Relapse is defined by immediate loss of advancement within 6 months after removal of distractors.

However, in the youngest patients requesting a facial advancement for impaired airways, psychological disturbances induced by the distorted morphology, or both (the most retruded cases), no stable occlusion can be obtained, and this adds to the risk of relapse the certitude of absence of further growth. Therefore, overcorrection is a transient answer, best achieved with distraction (Figure 53-4).

Two-Stage Strategy with Distraction

Distraction osteogenesis (distraction being the reverse of contraction) is a surgical option that allows a gradual separation of bone over time. This innovative approach was initially applied

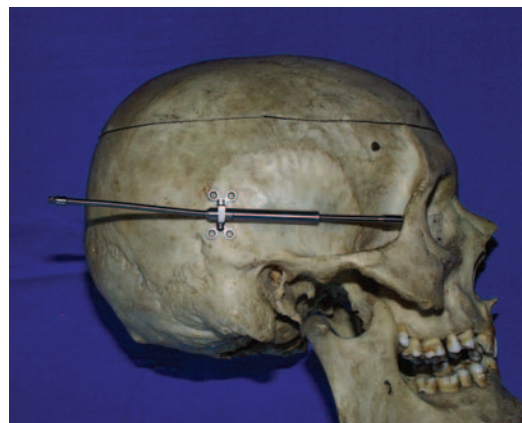


FIGURE 53-4 Posteriorly based temporozygomatic distractors for facial advancement (KLS Martin L.P.).

to the mandible (McCarthy and colleagues in New York since 1992⁸ and then Molina and Ortiz Monasterio in Mexico⁹) and was subsequently applied to the bones of the craniofacial skeleton.¹⁰⁻¹³

Since 1995, we have applied the techniques of distraction osteogenesis to Le Fort III facial advancements.^{13,14} This has allowed early correction of facial retrusion in younger children requesting treatment or requiring treatment for respiratory compromise (snoring, sleep apnea, or hypoxemia in more severe cases). Distraction allows hypercorrection in children without definitive dentitions. This approach therefore still requires two principal interventions (cranial surgery and facial distraction surgery), not to

mention the removal of the distractors, followed by minor facial procedures for refinements (genioplasty, rhinoplasty). This two-stage approach is still the classic management, despite the fact that distraction techniques allow further refinements in the treatment of even younger children. The distraction devices (see Figure 53-4) have been improved (KLS Martin L.P.), with some additive possibilities: swivelling axis to adapt to any bulging of the temporal fossa and flexible activation rods to limit the risk of dislocation of the devices (Figure 53-5). Among those improvements, a transfacial pin can be useful when the maxillary-zygomatic junction is fragile,¹⁵⁻¹⁷ and in this case, the distractor tips could be located on the bone or directly on the transfacial pin (Figure 53-6). The possibility of facial distraction is possible very early in life, especially in cases of major respiratory impairment, to avoid the necessity of a tracheostomy. Nevertheless, the genetic lack of growth of the upper jaw will remain, and further operations are necessary during childhood to reach the mandibular growth, which usually remains normal, although a growth alteration in the mandible may also exist, explaining some of the remaining respiratory impairments after successful midface advancements. If a Le Fort III osteotomy is performed early (before 6 years of age or earlier), a second one will probably be necessary later. Another osteotomy type, Le Fort I maxillary advancement, is often necessary after 14 years of age to permanently adapt a satisfactory occlusion. Subsequently, refinement with genioplasty and/or rhinoplasty comes, if necessary.

Distraction gives the possibility of overcorrection. Provided that some sufficient bony union is obtained by the distraction process and a long enough consolidation time, prevention of the immediate relapse is achieved. We recommend 3 to 4 months of consolidation time for a Le Fort III advancement, which is simple to order when the distraction devices are internal. In theory, the use of an external traction device such as the halo frame (rigid external distractor) is equally efficient to obtain satisfactory advancement, adding the possibility of a modification of vectors in the course of distraction,¹⁸ which in the case of Le Fort III brings the additive risks of vertical elongation of the orbits. But the main disadvantage of the halo frame is the necessity of an early removal, which might compromise the stability of the advancement obtained, although most authors report stable occlusion relationships. In our unit, we have been using almost exclusively internal devices for the past 10 years. In a few instances, in which an important overcorrection was



FIGURE 53-5 Second referral of a child with Apert's syndrome, aged 10 years, after various attempts of treatment, presenting with severe sleep apnea syndrome, desaturation at 70%, and complete loss of frontal bone after previous skull expansion. *A*, Front view. *B*, Lateral view with concave profile. *C*, Class III occlusal relationship. *D*, Lateral view of Le Fort III with internal distractors (the arrows designate bone grafts at the root of the nose and lateral wall of the orbits, where immediate advancement was obtained peroperatively). *E*, Clinical result at 1 year, front view. *F*, Clinical result at 1 year, lateral view. *G*, Clinical result at 1 year, occlusal view with Class I relationship. *H*, Clinical result at 2 years, front view. *I*, Clinical result at 2 years, lateral view. *J*, Clinical result at 2 years, Class I occlusal relationship. *K*, Control computed tomographic (CT) scan (front view); cranioplasty remains to be performed. *L*, Control CT scan (lateral view); cranioplasty remains to be performed.

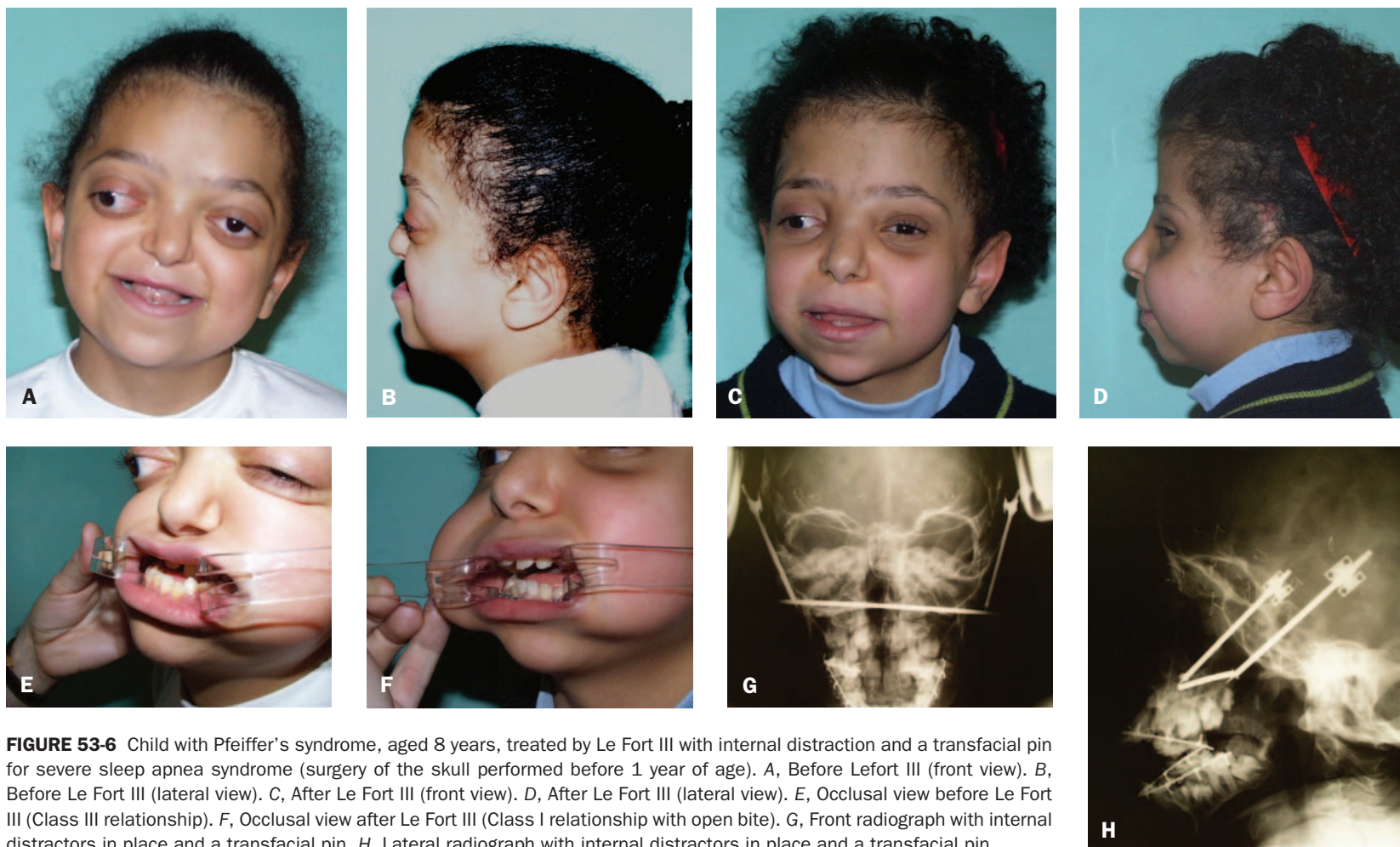


FIGURE 53-6 Child with Pfeiffer's syndrome, aged 8 years, treated by Le Fort III with internal distraction and a transfacial pin for severe sleep apnea syndrome (surgery of the skull performed before 1 year of age). *A*, Before Lefort III (front view). *B*, Before Le Fort III (lateral view). *C*, After Le Fort III (front view). *D*, After Le Fort III (lateral view). *E*, Occlusal view before Le Fort III (Class III relationship). *F*, Occlusal view after Le Fort III (Class I relationship with open bite). *G*, Front radiograph with internal distractors in place and a transfacial pin. *H*, Lateral radiograph with internal distractors in place and a transfacial pin.

not obtained with the internal devices alone, a combination of internal and external devices has been used (Figure 53-7). In these cases, an external halo frame ("pull") was added to the internal devices ("push") during the course of distraction and removed immediately when a satisfactory advancement was obtained, leaving the consolidation role to the internal devices, following Wall's proposal ("push and pull technique").¹⁹

In all of those cases of Le Fort III facial advancements, the use of bone grafts at the root of the nose and at the lateral frontozygomatic junction has been systematic since 1995 to limit the enlargement of the orbit, what was recently theorized as the advancement-rotation concept by Denny and colleagues.²⁰

The two-stage strategy for faciocraniosynostosis is reliable. Its main drawback is to delay facial advancement in severely faciocraniosynostotic patients.

Frontofacial Monobloc with Distraction

A one-stage radical surgical strategy has existed for a long time but was almost abandoned because of the risks involved. Frontofacial monobloc advancement allows simultaneous correction of the various deformities of the forehead and the face.²¹ But this procedure, which is technically complex, results in two inevitable consequences that are associated with not insignificant danger:

a retrofrontal dead space and a communication between this space and the upper part of the nasal airways as a result of the anterior cranial osteotomies. Major complications (meningitis, frontal bone necrosis) can ensue, particularly when the anterior cerebral reexpansion is not rapid enough, which is the case in adults or older children.^{22–25} These risks have resulted in the majority of teams drastically reducing the indications for classic monobloc advancements, despite certain technical modifications having been proposed to attempt to reduce these risks, specifically ensuring watertight repair of the anterior fossa floor and filling the dead space with a flap or split forehead.^{26–31}

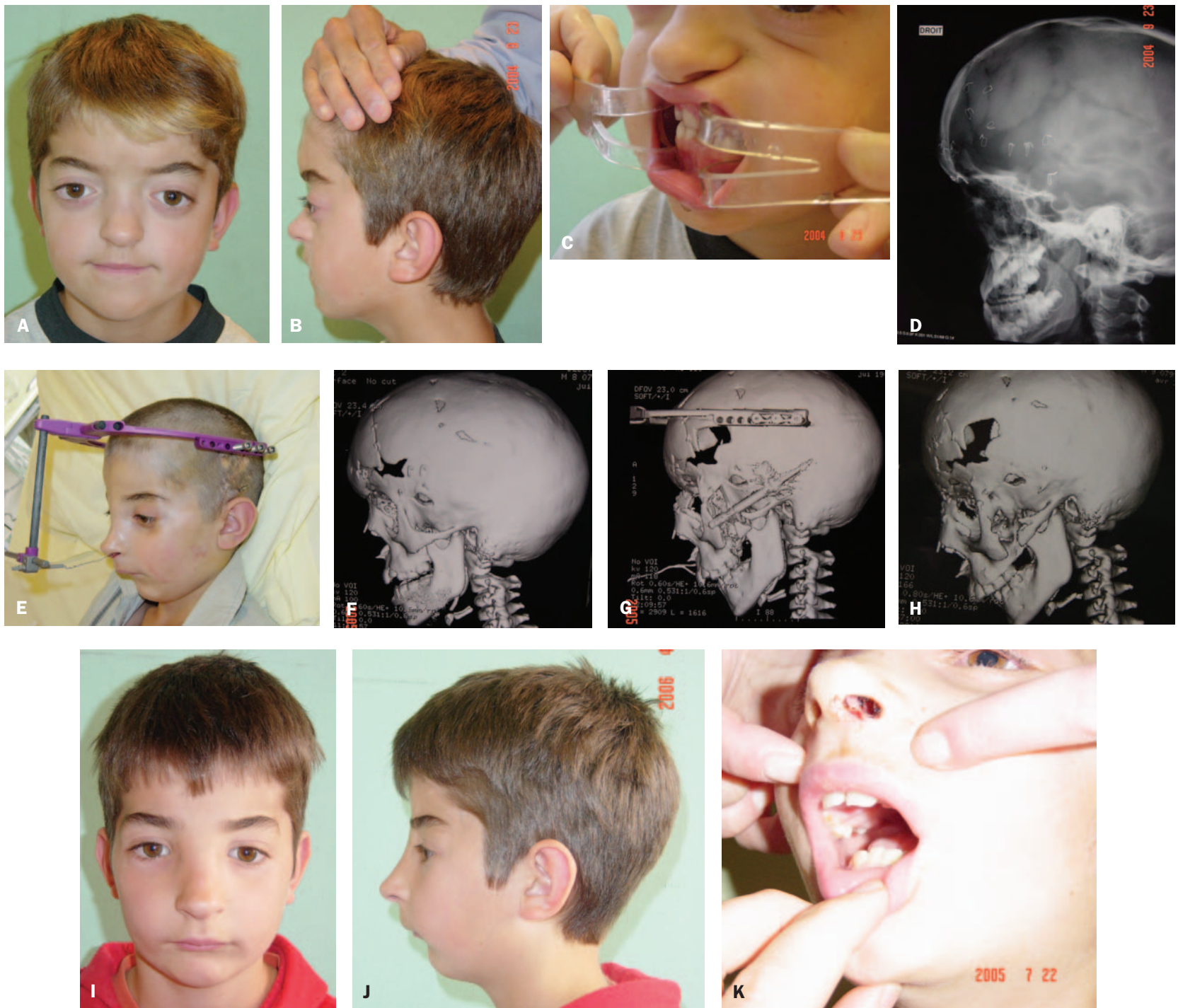


FIGURE 53-7 Child with Crouzon's disease, aged 9 years, who had already undergone surgery of the skull (fronto-orbital advancement before 1 year of age) and presented with severe apnea syndrome. Note the small mandible. A, Front clinical view. B, Lateral clinical view. C, Occlusal view (Class III relationship). D, Preoperative lateral cephalogram. E, Push and pull technique (the external device is left for 2 weeks and the internal device for 4 months). F, Preoperative lateral computed tomographic (CT) scan. G, Postoperative lateral CT scan in the course of distraction with internal and external devices (observe bone grafts at the lateral wall of the orbits). H, One-year follow-up of postoperative lateral CT, maintaining Class II apparent hypercorrection. I, One-year clinical follow-up with hypercorrection (front view). J, One-year clinical follow-up with hypercorrection (lateral view); mandibular lengthening will be carried out secondarily. K, One-year occlusal view with hypercorrection, maintaining Class II.

Distraction osteogenesis for frontofacial monobloc advancement has been sporadically performed since 1995^{32,33} and then developed

with external or internal distraction.^{34,35} We started our experience with quadruple distraction (Figures 53-8 and 53-9) in 2000 in our unit,³⁶ and

by mid-2006, we had operated on more than 50 cases with this technique with good results, especially with regard to the improvement in

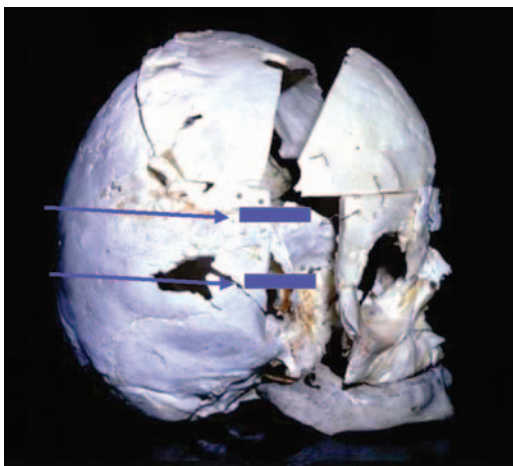


FIGURE 53-8 Design of frontofacial monobloc osteotomies with two pairs of distractors (quadruple distraction).



FIGURE 53-9 Design of paramedian periosteal flaps to seal anterior fossa.

respiratory function and the correction of exorbitism (Figure 53-10).³⁷⁻³⁹ The morbidity in the monobloc procedure can be significantly reduced as a result of distraction. We developed our protocol using two pairs of internal distractors, which seem to improve the effectiveness of the procedure while also decreasing its morbidity (see Figure 53-8). The progressive experience gained has resulted in gradual changes in the surgical technique and the distraction protocol. The risk of major infection has been lowered to a 3% ratio, regardless of whether a shunt was present.

Surgical Technique and Distractors for Frontofacial Monobloc Advancement

The surgical technique used is a frontofacial monobloc osteotomy, which is performed with removal of the frontal bone. The bilateral pterygomaxillary disjunction and the division of

midline structures are performed systematically, allowing operative mobilization of the complete frontofacial assembly.

The distractors used are devices manufactured by Martin-Medizin (KLS Martin L.P. group), with cylinders controlled by a percutaneous flexible device. Two types of distractors are necessary: frontocranial distractors used in the supraorbital region and temporomalar distractors with a rotatory axis (modifications of the distractors originally produced by MicroFrance) and positioned behind the zygomas. The control mechanism of the lower distractors is exteriorized posteriorly in all patients. The superior distractors are also exteriorized posteriorly. In one of our patients, however, the superior distractor was exteriorized anteriorly through the eyebrow in an approach we no longer recommend. The screws used to fix the distractors in place are resorbable or nonresorbable (2 mm diameter or with sonic welding pins). When frontozygomatic support is required, resorbable or metallic miniplates are used. In one of our patients undergoing secondary surgery, a reconstruction of the bandeau had to be undertaken and a transfacial pin (Staca, 2 mm), was connected to the anterior extremity of the two temporomalar retractors to reinforce the assembly and maintain control of the facial bipartition.

Distraction Protocol

The distraction protocol was classic for the first 15 patients, with a daily advancement of around 1 mm in each of the first four patients. The start of distraction was deferred to the seventh day. In the immediate postoperative period, no major infective episodes were noted, although a pyrexia of 37.5 to 38°C was present in all patients over the first few days.

The distraction was achieved with 0.9 mm daily advancement of the frontal distractors (three turns of 0.3 mm each) and with 1 mm daily advancement of the temporal distractors (two turns of 0.5 mm). Later in our experience, the daily rate was decreased. Distraction was continued to the maximal extent (20 mm) in the frontal distractors, which required some 14 to 17 days, depending on the initial position of the cylinders. The duration of temporozygomatic distraction was longer as the distractors do not have a limiting abutment and was around 20 to 28 days, until Class I dental occlusion was achieved. By the end of the distraction period, the control mechanisms of the distractors were sectioned flush with the skin and an arrangement was made to remove the distractors at least 3 months later in the first six patients. This consolidation period has progressively increased to 6 to 9 months in subsequent patients to decrease the degree of bony resorption and frontofacial retraction seen in distractors removed too early.

Discussion: One or Two Stages?

The principle of simultaneous correction of frontal and facial retrusion in faciocraniosynostosis is logical, but the inherent morbidity of a classic monobloc frontofacial advancement had been significant (25–50%). This morbidity has limited the indications of the procedure and must imply discussion at length prior to being undertaken.

The techniques of distraction first used in the mandible have been progressively applied to the rest of the craniofacial skeleton, which has led to a simplification of the procedures involved. The addition of distraction to the numerous other craniofacial procedures has permitted the progression of surgical interventions for morphologic modification while reducing their morbidity. This has been confirmed in the case of the monobloc advancement in various small series,⁴⁰⁻⁴⁴ as well as in our own experience.⁴⁵ We initially saw occasional minor complications, but with increased experience, these allowed a more defined protocol to be devised, as follows:

1. Systematic screening for respiratory impairment in faciocraniosynostosis by night sleep oxygenation monitoring. Sleep apneas are multifactorial in the faciocraniosynostotic patient, but the advancement of the midface definitely tends to correct the problem.^{7,46}
2. Surgical opening of the foramen magnum in case of cerebellum tonsillar herniation (Chiari-type malformation).⁴⁷ An existing tonsillar herniation may cause central respiratory disturbances or hydrocephalus and is a risk factor for frontofacial advancement with distraction because the augmentation of the skull volume is initially limited.
3. Frontal elevation to safely access the anterior cerebral fossa and to allow the remodeling of the forehead, which cannot be achieved without it.⁴⁸ In our experience, a lack of ossification in the coronal gap will exist whatever the technique.
4. Distractor fixation with metallic screws. A new resorbable fixation is currently being developed (sonic welding).
5. Reinforcement of bone with resorbable plates and screws, if required, in the frontozygomatic junction especially.
6. The use of Molina caps (KLS Martin, Germany) at the end of the temporomalar distractor. These caps allow good transmission of forces behind the zygomatic bone.
7. Obturation of nasal fossa dehiscence with double pericranial flaps. These flaps are transposed intracranially through the roof of the orbits (see Figure 53-9).
8. Complete pterygomaxillary disjunction, division of midline structures, and intraoperative postional control allow further distraction with limited forces.

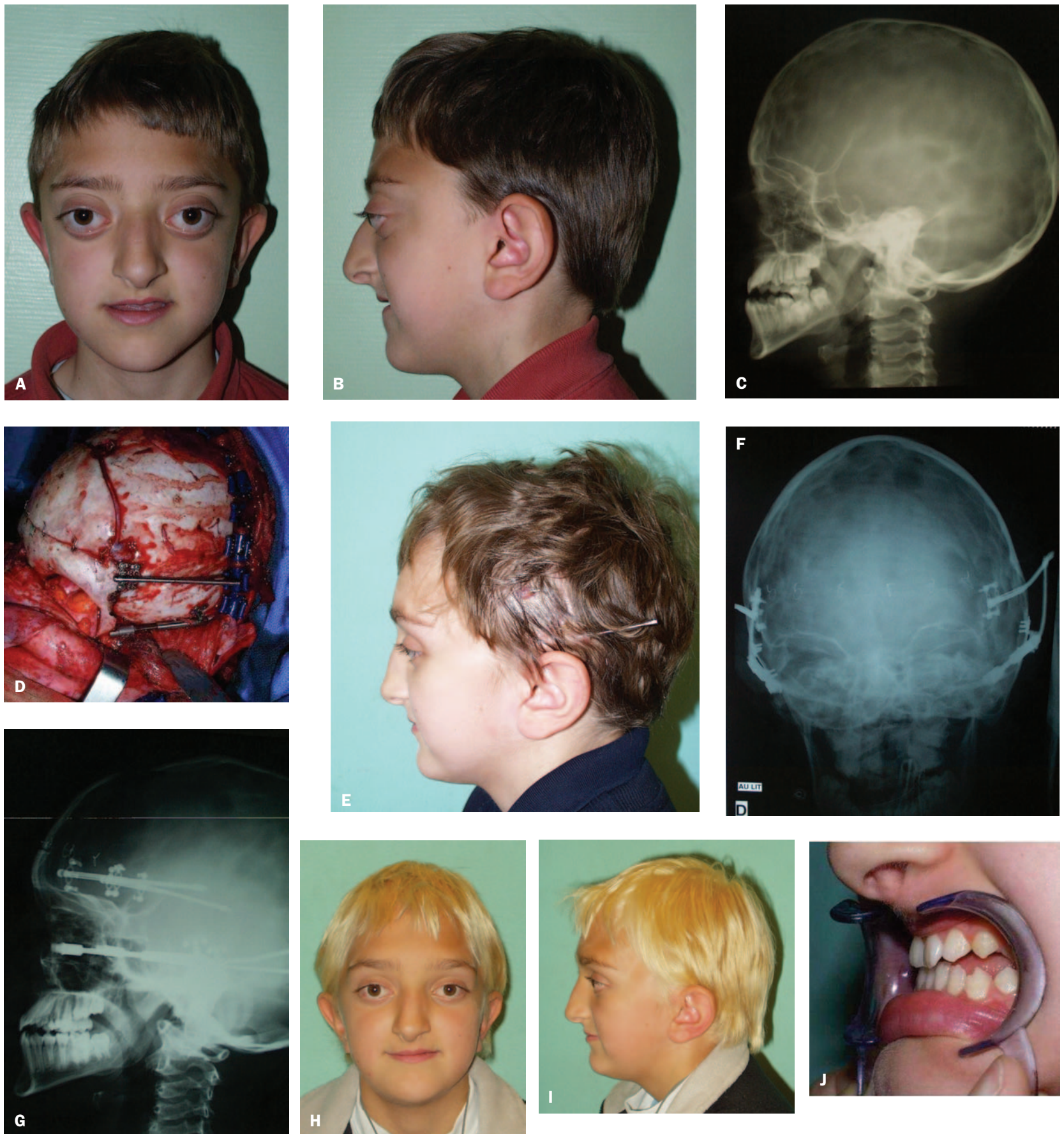


FIGURE 53-10 Child with unoperated moderately retruded Crouzon's disease, aged 12 years, with morphologic impairment and moderate sleep apnea syndrome, treated with monobloc frontofacial advancement and quadruple distraction. *A*, Front clinical view; observe exorbitism. *B*, Lateral clinical view. *C*, Preoperative lateral cephalogram (observe fingerprinting on the skull). *D*, Peroperative view with a left lateral pair (cranial and temporal) of distractors. *E*, Lateral clinical view after distraction. *F*, Postoperative frontal cephalogram after distraction. *G*, Postoperative lateral cephalogram after distraction. *H*, Front clinical view 2 years after removal of distractors. *I*, Lateral clinical view 2 years after removal of distractors. *J*, Occlusal view 2 years after distraction.

- 9. A 5 mm per-operative advancement performed in order to immediately augment the intracranial volume and to limit the risk of postoperative intracranial hypertension.
- 10. Bone paste application in the coronal region to encourage eventual reossification (mixture of autologous bone powder and fibrinogenic glue).
- 11. Maintenance in the intensive care unit with intubation for at least 24 to 48 hours to wait for diminution of initial swelling.
- 12. Prevention of a postoperative cerebrospinal fluid (CSF) leak by systematic lumbar drainage in case of a CSF leak seen peroperatively.
- 13. Distraction commencement is deferred until day 7 in case of a CSF leak.
- 14. Distraction rate of 0.5 mm/d.
- 15. Maintenance of the distractors in place for at least 6 months after the end of the distraction process (which renders external distractors contraindicated).

The protocol for antibiotic prophylaxis remains unstandardized as the monobloc procedure goes beyond the usual confines of surgery. The combination of the use of distractors with a complete frontofacial osteotomy poses the problem of a transitory implantation of

constantly contaminated prostheses. We currently opt for preventive antibiotic therapy of a short duration (48 hours) begun at induction, with the option of restarting therapy if signs of clinical infection are evident, after bacteriologic samples have been harvested. It could be, however, that broad-spectrum prophylactic antibiotic therapy is, in fact, useful for the entire period of distraction, despite the risk of the development of resistant bacterial strains.

The absence of ossification at the frontal osteotomy sites seems to contradict the usual osteogenicity found at most sites of distraction. It does not, however, pose any problem if the procedure is carried out early as secondary cranial osteogenesis remains possible until 2 years of age and if a tongue-and-groove osteotomy has been performed. This reinforces our conviction of the benefits of early distraction, before the age of 12 months, and allows the question of whether the one-stage strategy should be adopted as routine if morbidity is reduced and the stability of results is confirmed.

Since frontofacial monobloc advancement can be applied to more severe neonatal deformities and more minor, more slowly progressive deformities, much more frequent use of distraction for the technique is justified. This

early series has allowed us to define a one-stage strategy while remaining aware that minor secondary interventions remain indispensable to correct the ultimate growth disturbances of faciocraniosynostosis.

To reduce the risks of routine treatment of faciocraniosynostoses, a two-stage strategy has remained widely practiced for 20 years as it has allowed a dissociation of problems and a separation of risks.

The monobloc frontofacial advancement allows a combination of these two stages into one, with diminished risk.⁴⁵ It is probably the only way in which a patient can be weaned from a tracheostomy or an early tracheostomy can be avoided entirely (Table 53-1). The duration in time of this respiratory benefit remains to be evaluated with further follow-up (Figure 53-11).

Table 53-1 Improvement in Respiration after Monobloc Frontofacial Advancement with Distraction in a Subgroup of 35 Patients		
	Respiration Improved	Respiration Unchanged
24 primary	7	1
11 secondary	7	1

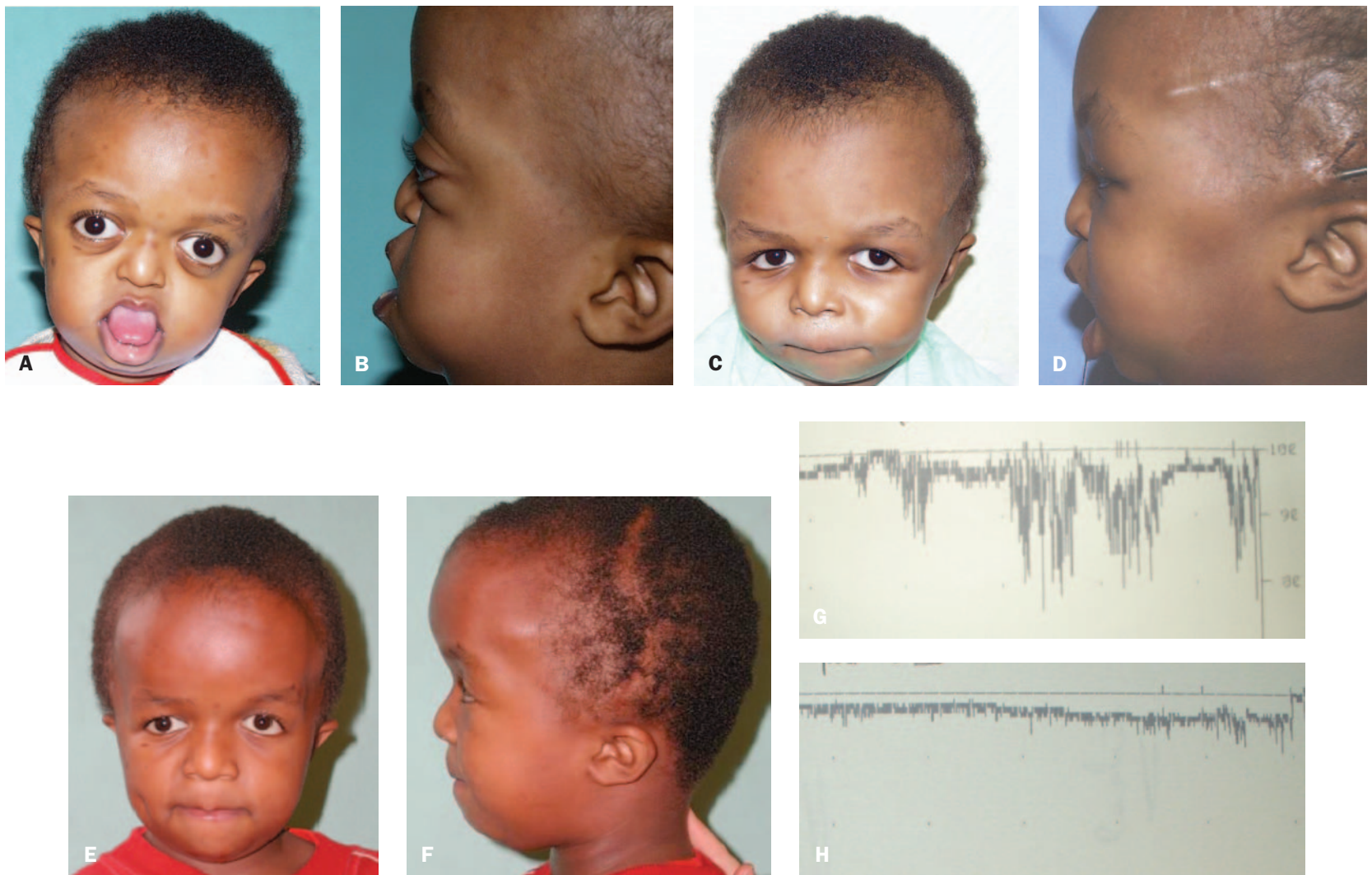


FIGURE 53-11 A 3-year-old child with unoperated Crouzon's disease with both morphologic and respiratory impairment treated with monobloc frontofacial advancement and quadruple distraction. *A*, Front clinical view. *B*, Lateral clinical view. *C*, Front clinical view after distraction. *D*, Lateral clinical view after distraction. *E*, Front clinical view after 4 years of follow-up, with a stable result. *F*, Lateral clinical view after 4 years of follow-up, with a stable result. *G*, Preoperative night oxygen saturography showing desaturation. *H*, Postoperative night oxygen saturography normalized after monobloc advancement.

Anterior or Posterior First?

In certain young patients, it clearly appears that the severity of the frontofacial retrusion is not so important and that, conversely, the flattening of the posterior aspect of the skull is impressive. This occurs frequently in Apert's syndrome. In these cases, the strategy of posterior expansion first, initially proposed by Sgouro and colleagues, is an interesting option.⁴⁸ We have adopted this strategy for many years, but the conventional posterior approach without distraction is a dangerous procedure as it goes across the main posterior venous sinuses. Conversely, to our management of craniosynostoses, which provide satisfactory results with remodeling surgical techniques without distraction, the posterior expansion of the skull merits this technique. Based on the work performed by Lauritzen, Gwalli and colleagues with spring-assisted distraction,⁴⁹ we performed posterior expansion with springs in infants. This

is based on a distraction concept across patent (nonfused) lambdoid sutures,⁵⁰ which allows a significant decrease in bleeding in comparison with the conventional approach. The posterior expansion allows us to wait until the anterior skeleton becomes more solid, which will make the frontofacial advancement even simpler.

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Contra-Angle Technique for Rigid Fixation of the Sagittal Split Ramus Osteotomy

Anthony Farole

For the last 17 years, I have employed a transoral contra-angle technique for rigid fixation of the mandibular sagittal split ramus osteotomy (SSRO). The technique was originally published in 1992, when we reported our results with 70 cases.¹

To date, 700 cases using the technique have been performed by the author, with predictable results. Minor refinements have been made, and these have improved the ease and accuracy of the method. These are discussed in this chapter. Rigid screw fixation and immediate or early mobilization of the mandible following mandibular ramus surgery is often desired by surgeons and patients. The advantages and disadvantages of rigid fixation of the SSRO have been described by other authors.²⁻⁶

The two most popular techniques for drilling and placement of screws are (1) percutaneous placement through a cheek incision and (2) transoral oblique placement. One disadvantage of the transoral oblique method using a straight drill is the difficulty of and often the impossibility of placing the screw hole, and therefore the screws, at right angles to the bone. Torquing of the segments could result from oblique screw placement. Also, an oblique placement technique can limit the number of screws placed owing to the mandatory oblique drilling technique, which, by nature, may not allow the most proximal hole to engage the distal segment even though the proximal segment can be engaged.

The initial reasons for development of the contra-angle method included the elimination of extraoral incisions, which occasionally create visible scars required for the percutaneous technique, and the ability to more predictably enable multiple screws to be placed, which is sometimes not possible when straight intraoral drills are used. As I describe, other advantages became apparent as the technique was used in excess of 700 cases to date.

Technique

The technique is illustrated on the accompanying DVD both in vivo and on a dry skull. A routine SSRO is completed as originally described by Obwegeser and modified by Hunsuck and others. Intermaxillary fixation is applied as usual. Initially, a high or low wire was used, as described by Epker and others; however, wiring of the segments has been abandoned during the last 2 years as it has become unnecessary for stabilization of the proximal segment. I use a “best fit” feel of the condylar segment, passively seating the condyle in the glenoid fossa. The inferior border of the proximal segment is rotated in its desired position. A toe-out retractor is used in the operator’s left hand to stabilize the proximal segment. A Stryker TPS system (Stryker, Kalamazoo, Michigan) is used with a contra-angle handpiece, using the head with a 1:1 gear ratio to drill the first hole through the proximal and distal segments to the depth of the medial aspect of the distal segment. The length of the drill inserted into the latch insertion handpiece is generally 15 mm; however, slightly longer or shorter drill lengths can be used and manufactured by the bone plate and screw manufacturer. The surgical assistant or scrub nurse changes the contra-angle head to the 256:1 gear ratio by simply pulling off the 1:1 head and inserting the reduced head. The assistant is told the length of the screw desired by the surgeon prior to switching the heads. In so doing, the desired screw is snapped onto the screwdriver head, which has been mounted prior to starting surgery. This preparation ensures a rapid and smooth transition from the drilling to screw insertion steps. The driver is either a cruciate or Phillips-type head or a tapered square press fit depending on the rigid fixation manufacturer or screw type desired. A single-slotted screw and straight slot driver are not recommended as slippage occurs when using a single-slotted screw. I prefer and use either the cruciate or square tapered driver, which ensures an excellent fit of the driver to the screw head. The surgeon then carries the

handpiece loaded with the first screw and inserts the screw using the power system with irrigation. The driver will almost always disengage when the screw is fully inserted and fits securely against the proximal segment. With the proximal segment stabilized with the distal segment after the first screw is placed, a second and a third screw are placed by repeating the process. Because the screws are placed perpendicular to the mandibular bone, it is easier to select different patterns of screw placement above or below the mandibular bone. These patterns can include three screws above the position of the inferior neurovascular bundle or two above and one below or two below and one above, dictated by the best available mandibular bone. Foley and colleagues have shown in an in vitro system that segment distortion and displaceability occurred less when a staggered, inverted-L pattern was used as opposed to when a linear pattern superior border technique only was used.⁷ The contra-angle technique allows great flexibility in screw pattern placement. In the event that only one or two screws can be placed owing to short overlap of the bony segments (which is seldom the case), I will use a monocortical bone plate that spans the vertical osteotomy between the proximal and distal segments. The addition of a monocortical plate placed using the contra-angle technique provides for adequate stabilization of rigid fixation of the segments. In this case, a four-holed plate is used; two screws placed each on the proximal and distal segments.

A few points warrant further discussion. The use of this technique requires practice and, like any method not routinely used, entails a learning curve. It is recommended that the surgeon practice this technique on a cadaver, dried skull, or alloplastic model prior to using it clinically to improve success and minimize frustration, which will result in shortening the learning curve.

This is true whether the surgeon is a novice or an experienced orthognathic surgeon, but,

generally, the experienced surgeon will have a shorter learning curve. It is well worth the effort as the rewards are a benefit to the surgeon and the patient. These include shorter operating time and improved surgical accuracy. As in any technique of rigid fixation of the SSRO, the final occlusion is only as good as the placement of accurate inter-maxillary fixation set into the desired position and proper seating of the proximal segment. No technique will ensure proper planned occlusion if these steps are compromised.

Proper use of a toe-out retractor will allow adequate room lateral to the mandible to apply the technique described. A simple 90° angulation of this retractor turned perpendicular to the lateral surface of the mandible during screw insertion while using the gear reduction handpiece provides good retraction while at the same time eliminating interference with the contra-angle handpiece. Attention to this seemingly minor but important detail illustrated in the DVD

will eliminate frustration in employing this method. Lastly, the contra-angle technique may prove to be useful during rigid fixation of high Le Fort level osteotomies in the zygomatic buttress area.

I have described the advantages of the contra-angle technique.⁸ These include

- Perpendicular placement of screws
- Avoidance of an extraoral incision, which has the potential for scarring and facial nerve injury
- Equal torque or tightness applied to each screw by presetting the power source to the desired revolutions per minute with a default torque. This leads to less proximal segment torque or rotation and promotes physiologic positioning of the condyle-disk-fossa relationship (L. Wolford, personal communication, February 1991).⁸
- Rapid drilling and screw placement (after an appropriate learning period)

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Distraction Osteogenesis: The New Frontiers

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Endochondral bone lengthening by osteotomy and gradual distraction has been described for nearly a century. Since its initial description by Alexander Codivilla, distraction osteogenesis (DO) has become an important treatment option for congenital or acquired limb-length deficiency and mandibular hypoplasia. This technique has revolutionized orthopedic tissue engineering, and its more recent application to the craniofacial skeleton has significantly augmented our armamentarium for reconstructive procedures.

In an elegant series of pioneering experiments, the Russian orthopedic surgeon Gavril Ilizarov identified the physiologic factors governing osseous regeneration during endochondral DO.¹⁻⁴ Ilizarov found that successful distraction depends on the stability of fixation, the rate of daily distraction, and the preservation of the local soft tissue envelope and vascular supply.^{1,2,4-8} Additional work has described the biomechanical, histologic, and ultrastructural changes associated with DO.^{2,9-11} Clinically, this work has translated into the latency period (the period of time after osteotomy and prior to the initiation of distraction), the rate and rhythm of distraction (amount and frequency of movements), and the consolidation period (period of time the patient is maintained in rigid external fixation).

Using a canine model, Snyder and colleagues were the first to adapt these endochondral distraction principles to the membranous craniofacial skeleton.¹² Snyder's success was a considerable technical accomplishment that ignited the field of craniofacial DO and created the momentum for numerous experimental surgical models.¹³⁻¹⁶ These large animal models have refined the technical principles of craniofacial distraction, but the molecular mechanisms governing this process remain largely unknown. We believe that understanding these fundamental biomolecular mechanisms may reduce complications (eg, fibrous union) and enhance bone regeneration through the application of novel

recombinant proteins or gene transfer techniques. Looking forward into this new millennium, one can imagine a time when major reconstructive surgery and bone grafting will no longer be necessary for the craniofacial skeleton. For example, gene-modified DO and miniature, multiplanar, remote-activated, biodegradable distraction devices may lead to minimally invasive approaches for the treatment of mandibular deficiency, midface retrusion, cranial vault remodeling, cleft palate, microphthalmos, and adult calvarial defects.

Recently, our laboratory has described a rat mandibular distraction model that provides an excellent environment for deciphering the molecular mechanisms that mediate DO (Figures 55-1 and 55-2).^{17,18} Using this model, we have demonstrated that gradual DO stimulates the

production of osteoinductive growth factors (eg, TGF- β_1) and extracellular matrix molecules (eg, collagen I and osteocalcin).¹⁸ Furthermore, we have begun to investigate the molecular mechanisms by which successful DO (ie, healing with a bony regenerate) differs from ineffective DO (ie, healing with a fibrous union). Using this paradigm, we have demonstrated that gradual mandibular distraction, in contrast to acute lengthening, results in net accumulation of bone-specific extracellular matrix (ECM) products. In addition, these data suggest that diminished bone formation associated with acute mandibular lengthening may be, at least in part, due to a decrease in the production of bone scaffold (collagen I) and its mineralization (osteocalcin). An increase in expression of the tissue inhibitor of metalloproteinase 1 (TIMP-1), an important regulator of ECM turnover, also suggests that gradual distraction may promote bone formation in the interfragmental gap, by regulating the turnover of ECM products. For example, TIMP-1 may inhibit the degradation of the ECM, shifting the balance away from proteolysis and in favor of bone deposition. Factors governing neoangiogenesis during mandibular DO appear considerably more complex, and our laboratory continues to aggressively investigate the role of signal molecules, transcription factors, and homeobox genes that are hypothesized to shape the nascent vasculature.

In this chapter, we present the hypotheses and current research that have furthered our knowledge of the molecular mechanisms that govern distraction osteogenesis. To date, most of the benchwork has been performed on endochondral bone, and we will reference this work as a foundation for future studies in the membranous craniofacial skeleton. We believe that novel systems like the rat model will facilitate our understanding of the biomolecular mechanisms that mediate membranous DO, and will ultimately guide the development of targeted strategies designed to accelerate bone healing.

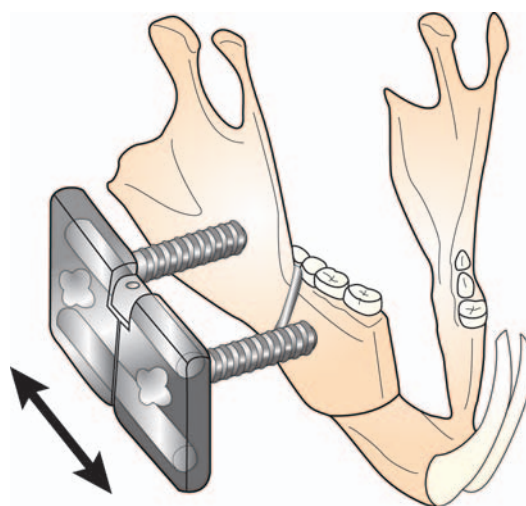


FIGURE 55-1 Schematic of a customized distraction device attached to a rat mandible. Activation of the device produces distraction of the osteotomized bone edges perpendicular to the direction of the osteotomy. The arrows mark the direction of distraction. The osteotomy is located between the second and third molars.

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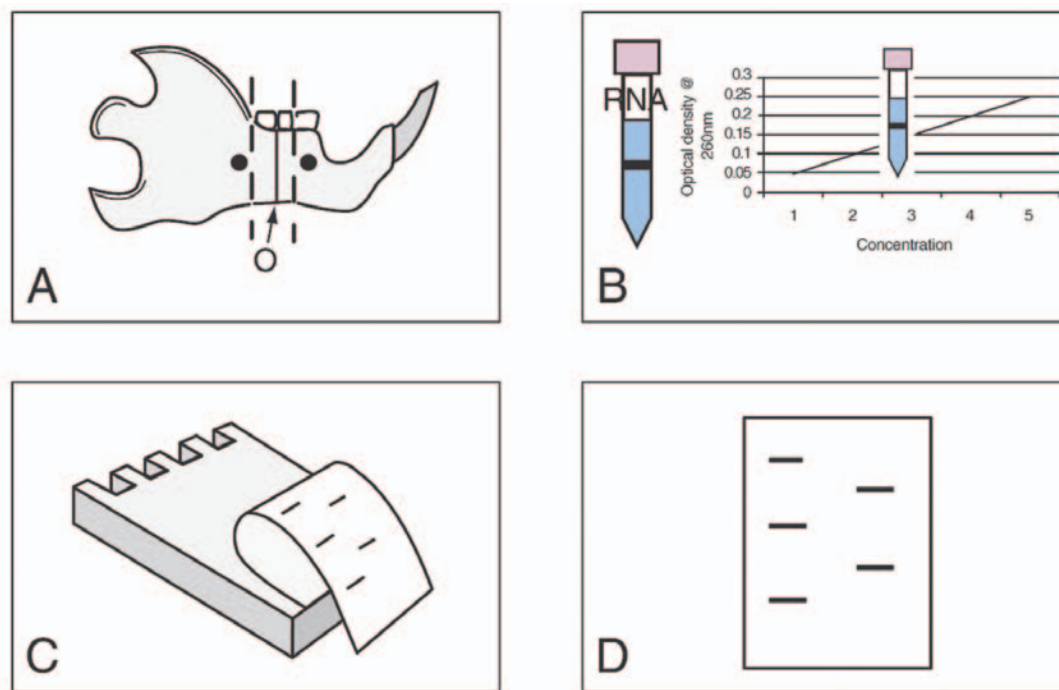


FIGURE 55-2 Overview of Northern analysis methods. A, Line drawing of the mandible. Mandibles were harvested, skin and soft tissues were removed, and the area bound anteriorly and posteriorly by the pins was dissected (O = osteotomy). B, The distraction regenerate was homogenized, and total cellular RNA was extracted and quantitated. C, Total cellular RNA (20 μ g) was fractionated on a 1% denaturing gel and transferred to a nylon membrane. D, Membranes were probed with radioactive cDNA probes, and digitalized images were captured and quantified.

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Recent studies have implicated a growing number of cytokines that are intimately involved in the regulation of bone synthesis and turnover.^{19–22} The actions of the transforming growth factor β s (TGF- β_1 , - β_2 , - β_3), bone morphogenetic proteins (BMPs), insulin-like growth factor I (IGF-I), and basic fibroblast growth factor 2 (FGF-2) have been best characterized and will be discussed in this text.²³

Transforming Growth Factor β s

The TGF- β s appear to have a particularly significant role in the regulation of bone formation, since they strongly promote collagen production in osteoblasts and up-regulate the production of noncollagenous ECM proteins implicated in the regulation of mineralization and bone turnover (reviewed by Joyce and colleagues and Hiltunen and colleagues).^{24,25} In addition, TGF- β s retard the degradation of ECM molecules by simultaneously inhibiting the production of matrix metalloproteinases and up-regulating the synthesis of TIMP-1.²⁶ Furthermore, TGF- β s stimulate osteoprogenitor cells and inhibit the production and activation of osteoclastic cells.^{27,28}

Osteoclasts have an interesting role in TGF- β activation and fracture healing (ie, post-osteotomy), since they may initiate a cascade that results in the release of latent TGF- β from bone

matrix. This is a particularly important point, since TGF- β s are secreted as inactive precursors (latency-associated peptides) that are covalently associated with a 70 kDa pro-region.²⁹ In most tissues, the inactive TGF- β -latency-associated peptide complex is also bound to a 190 kDa latent TGF-binding protein that facilitates its storage in the ECM.^{30–32} Matrix TGF- β activation occurs when osteoclasts enzymatically cleave the latency-associated peptide and latent TGF-binding protein, releasing the single-chain mature peptide.³² The release of active TGF- β from the bone matrix may, in turn, suppress osteoclast activity and promote net deposition of bone in the interfragmental gap.

Using Northern blots to analyze distracted rat mandibles, we have demonstrated a 2.5-fold increase in TGF- β_1 messenger ribonucleic acid (mRNA) expression 3 days after osteotomy (ie, end of the latency period), as compared with sham-operated bone.¹⁸ During the early phases of distraction, TGF- β_1 mRNA expression increased to 3 times normal levels and remained elevated throughout the distraction period before returning to baseline by the end of the fourth week of the consolidation period. Immunohistochemistry localized TGF- β_1 to the inflammatory cells within the fracture hematoma during the latency period. During the early phases of distraction,

osteoblasts, primitive mesenchymal cells, the ECM, and connective tissues adjacent to the osteotomy site also expressed intense TGF- β_1 . During the consolidation phase, TGF- β_1 immunostaining was primarily confined to osteoblasts at the corticotomy surface and within the matrix of the distraction gap. After a 4-week period of rigid external fixation, TGF- β_1 expression was limited to osteoblasts within the remodeling bone.¹⁸

The augmentation of osseous healing by TGF- β s has been studied in many different animal models, isoforms, doses, and routes of delivery.³³ Although rigorous comparisons between these studies are difficult, most publications report that TGF- β s enhance bone formation in vivo. For example, TGF- β_1 augments bone healing in critical size defect models and significantly enhances the biomechanical properties of bone.^{34–36} Miller and colleagues found that TGF- β_2 increases cancellous bone formation in rats.³⁷ Although it seems likely that TGF- β s should enhance regenerate bone formation during DO, the only study published on the exogenous application of TGF- β_1 in a long bone-lengthening DO model failed to demonstrate any effect.³⁸ Despite this report, more work is needed to evaluate the efficacy of the TGF- β s in a membranous bone DO model.

Bone Morphogenetic Proteins

The BMPs are a 20-member family of secreted growth factors belonging to the TGF- β superfamily. These pleiotropic signaling molecules regulate a myriad of cellular processes based on their extracellular concentration gradient.^{39–41} For example, at low concentrations they promote chemotaxis and cellular proliferation, whereas at high concentrations they favor cellular differentiation and bone formation.^{39,42} Studying gene expression during rat long bone DO, Sato and colleagues demonstrated that the mechanical tension-stress effect of endochondral DO has a significant effect on BMP transcription.²⁰ During the 4-day latency period, BMP-2 and -4 showed similar patterns of intense expression in the chondroid bone cells and their progeny. High levels of BMP-2 and -4 gene expression continued throughout the consolidation period along the ossification front and in the fibrous interzone, separate from the bony trabeculae. Interestingly, BMP-6 and -7 were not up-regulated during DO.²⁰ Using immunohistochemistry, Rauch and colleagues localized BMP-2, -4, and -7 expression to the periosteal region of the rabbit tibiae during the latency period.⁴³ In the distraction phase, the authors found intense BMP-2, -4, and -7 staining in the interfragmental gap. The intense immunolocalization continued throughout the distraction period, before tapering off during consolidation.

Interestingly, recent work has indicated that osteoblasts exposed to BMPs are stimulated to

secrete an osteogenic antagonist, called noggin.⁴⁴ This antagonist binds to and inactivates BMPs, thereby preventing them from interacting with their cognate receptor and effectively reducing their extracellular concentration gradient. The induction of noggin by BMPs in osteoblasts may suggest the existence of a protective mechanism to prevent excessive exposure of skeletal cells to BMPs. Future work in DO must investigate the expression of noggin in the distraction regenerate and possibly design techniques to limit the reciprocal noggin induction, tipping the balance in favor of osteogenesis, when indicated clinically.

Insulin-like Growth Factor I

IGF-I is a ubiquitous skeletal growth factor. Both in vivo and in vitro data suggest that IGF-I stimulates or facilitates osteoprogenitor cell mitosis and differentiation, thereby increasing the number of functionally mature osteoblasts.⁴⁵ Interestingly, IGF-I expression in the distracted callus appears to be time-dependent.²¹ Lammens and colleagues reported an initial increase in serum IGF-I levels during the distraction period, followed sequentially by an increase in skeletal IGF-I levels in both the distracted callus and surrounding bone.⁴⁶ The initial rise in systemic levels may be the result of IGF-I being released from the surrounding soft tissues during DO.⁴⁷ In further support of the role of IGF-I during the early stages of DO, Schumacher and colleagues found an increase in the level of periosteal IGF-I in the lengthened rabbit tibia, only during active bone lengthening.⁴⁸ Finally, Tavakoli and colleagues found low-level expression of IGF-I after 20 days of distraction and after 20 days of consolidation.²² Collectively, these data strongly suggest that IGF-I may play an important role during early DO.

To date, there are surprisingly few IGF-I DO therapeutic studies. Stewart and colleagues applied exogenous IGF-I in a rabbit model of mandibular DO and observed an enhanced mineral apposition rate during the DO. Interestingly, local IGF-I infusion facilitated bony union even at distraction rates (3 mm/day) that routinely lead to fibrous union.⁴⁹ In summary, IGF-I seems to be an interesting candidate to enhance bone formation during DO; however, its ideal doses and method of delivery still remain unknown and deserve further investigation.

Fibroblast Growth Factors

The FGFs are a highly conserved family of at least 19 closely related monomeric peptides. These growth factors act in concert with heparin sulfate-containing proteoglycans to modulate cell migration, angiogenesis, bone development and repair, and epithelial-mesenchymal interactions.⁵⁰⁻⁵⁴ FGF-2 is the most abundant ligand, and it has

been shown to stimulate osteoblast proliferation and enhance bone formation in vivo and in vitro.⁵⁵⁻⁵⁷ FGF-2 expression is elevated in fracture healing, and exogenously applied FGF-2 accelerates osteogenesis in critical size bone defects and fracture sites.⁵⁸⁻⁶⁰ Furthermore, the FGF-2 signaling cascade augments the expression of TGF- β and its myriad of pro-osteogenic effects.⁶¹

Based on immunohistochemical studies in a sheep distraction model, Farhadieh and colleagues observed FGF-2 expression in all distraction samples, with increased FGF-2 staining in the high-rate distraction group (4 mm/day).²⁸ Using a rabbit model of long bone DO, Okazaki and colleagues reported a significant effect of a single local injection of recombinant human FGF (rhFGF-2) at the end of the distraction period on the bone formation of the distracted callus.⁶² FGF-2 injection significantly increased the bone mineral content of the regenerate during the consolidation period. This may indicate that FGF-2 can be used as a potential method to shorten the overall length of the DO protocol. Again, it is intuitive that such a powerful osteogenic cytokine should have a positive effect on bone formation during DO; however, its dose and method of application still have to be defined to become clinically relevant.

Collagenous Extracellular Matrix Proteins

The production of ECM components has been intensively investigated during endochondral fracture healing and long bone development.⁶³ Only recently have researchers begun to investigate ECM formation during DO. The collagens are a major component of the ECM and appear to play a critical role in bone formation by facilitating the formation of early bone spicules extending from the fracture (ie, osteotomy) edges toward the center of the interfragmental gap. These spicules form the primary mineralization front associated with successful osseous union.^{4,10} Collagen expression during endochondral fracture healing can be organized into the inflammatory, reparative, and ossification stages.⁶⁴ Osteogenesis associated with DO differs from fracture healing in that both endochondral and membranous regenerate formations occur primarily through membranous ossification (ie, without a cartilaginous intermediate).^{1,10,11,65} The inflammatory stage of endochondral fracture healing is characterized by the disruption of nutrient vessels, hematoma formation, cell death, and inflammatory cell infiltrate. This phase is associated with an acute up-regulation of Type III collagen localized primarily to fibroblastic cells of the fracture callus.⁶⁴

The reparative phase, initiated approximately 7 to 14 days post-fracture in endochondral bones, is characterized by appositional growth of

new woven bone as well as a cartilaginous matrix, and the production of Type II collagen expression by chondrocytic cells.^{63,64,66,67} Expression of Type IX collagen closely mirrors that of Type II collagen, since it has been shown to be linked to the surface of Type II collagen fibrils.⁶⁸ Type X collagen expression within hypertrophic chondrocytes is up-regulated toward the end of the reparative phase of bone healing and has been interpreted by some authors to be an indicator of endochondral ossification.⁶⁹

Remodeling and ossification of the cartilaginous matrix represents the final phase of endochondral fracture healing. This phase begins about 2 weeks after fracture and is characterized by replacement of Type II with Type I collagen fibrils.^{25,67,70} Activated osteoblasts migrate along newly formed bone trabeculae and haversian systems, and continue to remodel the healing fracture for weeks. Warren and colleagues demonstrated that collagen I expression is similarly up-regulated during rat mandibular DO, beginning 10 days after osteotomy (corresponding to the end point of the distraction phase) and continuing well into the consolidation phase.⁷¹ The temporal and spatial changes in collagen expression and fibril orientation, in gradually distracted bony regenerates, appear to facilitate the formation of early bone spicules, extending from the osteotomy edges toward the center of the distraction gap.⁷¹

Noncollagenous Extracellular Matrix Proteins

Noncollagenous matrix proteins are a second major class of ECM components. They have an important role in regulating ossification and bone remodeling (reviewed by Sandberg and colleagues).⁶³ Examples of these noncollagenous ECM proteins include (1) osteonectin (ON), a secreted calcium and Type I collagen-binding glycoprotein thought to have important functions in the regulation of calcium turnover, bone remodeling, and initiation of mineralization²⁵; (2) osteopontin (OPN), a phosphorylated glycoprotein thought to promote adhesion of osteoblasts to remodeling ECM⁶³; and (3) osteocalcin (OC), the most abundant noncollagenous matrix protein in bone. This γ -carboxyglutamic acid-containing protein is only produced by mature osteoblasts, odontoblasts, and chondrocytes.⁷²⁻⁷⁴ Although its exact function is unknown, osteocalcin has purported roles in the regulation of mineralization, and serum concentrations correlate with histomorphometric indices of newly formed bone.^{73,75}

ON and OC mRNAs have been localized to osteoblasts within the endosteum of normal and fractured adult bone, whereas OPN is only expressed by osteoblasts shortly after fracture.^{63,76}

ON expression can also be localized to hypertrophic chondrocytes at a fracture site, and there is evidence to suggest that it has a role in the initiation of mineralization.⁷⁰ OC expression is acutely down-regulated during the early phase of fracture healing, but its expression increases during active ossification of the fracture callus.⁶³

Warren and colleagues have studied osteocalcin expression during rat mandibular gradual DO and acute lengthening (Figure 55-3).⁷¹ The high level of osteocalcin expression in normal (ie, sham-operated) mandibular bone precipitously declined after osteotomy in both experimental groups. In acutely lengthened animals, osteocalcin levels remained below 50% of basal expression throughout the distraction and consolidation periods. In marked contrast, osteocalcin expression in gradually distracted mandibles progressively increased from mid-distraction

through the consolidation period. Immunohistochemistry localized the osteocalcin to intensely staining osteoblasts in the distraction regenerate. These findings imply that osteocalcin production temporally and spatially correlates with successful DO. In the future, serum osteocalcin levels may be used to monitor successful distraction and provide an objective end point for successful bony union during the consolidation period. Further research is necessary to accurately define the roles of these noncollagenous ECM proteins and identify sites for targeted biologic interventions.

Neoangiogenesis

In addition to the formation of osteoid, successful distraction requires revascularization. Following osteotomy, vascular disruption of nutrient arteries, release of lysosomal enzymes from necrotic bone edges and soft tissues, and vasoconstriction

of periosteal and medullary arteries result in the formation of a hypoxic interfragmental zone of injury.^{6,77} Together, these stimuli are thought to serve as a catalyst for neovascularization, eventually leading to an 8.5-fold increase in blood flow to the distracted segments.^{7,65,78} Although neovascularization is essential for osseous regenerate formation, the molecular mechanisms mediating this process still remain to be fully characterized.⁹

Since TGF- β_1 (a potent stimulus for vascular endothelial growth factor, VEGF) increases post-osteotomy or fracture, and hypoxia stimulates osteoblasts to up-regulate VEGF, our laboratory has compared VEGF mRNA and protein production in gradually distracted and acutely lengthened mandibles.^{18,71,79-81} Immunohistochemistry equally localized VEGF protein to osteoblasts and endothelial cells of the interfragmental gap of both experimental groups. Analysis of VEGF mRNA expression demonstrated a modest increase 5 to 7 days after osteotomy in both experimental groups, compared with controls. Although elevated VEGF expression continued throughout the distraction and consolidation periods, surprisingly, there appeared to be no relative difference in VEGF mRNA expression between successful (gradual distraction) and ineffective (acute lengthening) DO.

This finding may be due to the lack of sensitivity of Northern analysis for low copy number mRNA. In a mouse model of mandibular DO, comparison of gene expression between groups treated with gradual versus acute DO was performed using a quantitative real-time reverse-transcription polymerase chain reaction (RT-PCR).⁸² Quantitative real-time RT-PCR demonstrated that groups treated with gradual DO, resulting in complete bony union, exhibited up-regulation of mRNA for VEGF, in contrast to groups treated with acute lengthening, which formed fibrous non-union.

Recently, our laboratory demonstrated that when angiogenesis is blocked, using TNP-470, an angiogenic inhibitor, in gradual mandibular distraction of rats, fibrous non-union resulted, similar to groups that underwent acute mandibular distraction.⁸³ In both groups, gross histology and immunohistochemical localization of the platelet endothelial cell adhesion molecule revealed an absence of angiogenesis.

Alternatively, as we discover that reparative processes may recapitulate developmental morphogenesis, it seems likely that neovascularization during DO is a coordinated process, requiring integrated signaling through a number of ligand-activated receptors that are specifically expressed on endothelial cells in a temporally coordinated manner.^{84,85} Analysis of VEGF receptor isotypes, angiopoietins (Ang-1 and Ang-2), and the Tie receptors (Tie-1 and Tie-2) may provide further

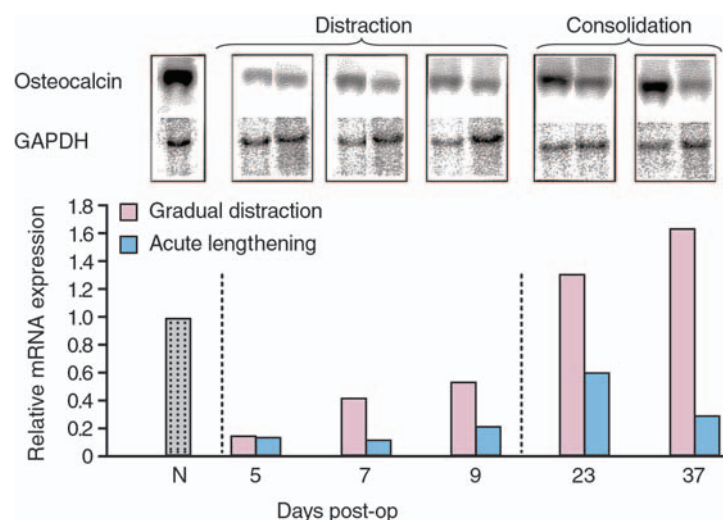


FIGURE 55-3 Representative Northern analysis of osteocalcin expression during rat mandibular distraction osteogenesis and acute lengthening. Sham-operated (N) osteocalcin expression is shown for comparison. Data are presented as the average relative mRNA expression (arbitrary units) of two separate Northern analyses. Sham-operated mandibular tissue is assigned a value of 1. Membranes were exposed to phosphor screens, and digitalized images were captured with a PhosphorImager (Molecular Devices, Sunnyvale, CA). Data were quantified using *ImageQuant* (Molecular Devices, Sunnyvale, CA) software. To ensure equal loading and RNA transfer, all membranes were stripped and reprobed with glyceraldehyde-3-phosphate dehydrogenase (GAPDH). Osteocalcin expression was sharply down-regulated (5-fold) in both experimental groups, compared with sham-operated mandibles (N), shortly after the osteotomy. In gradually distracted animals, osteocalcin expression slowly increased during the distraction period, reaching nearly 50% of normal levels by the final day of distraction (postoperative day 9). The increase in osteocalcin expression in gradually distracted mandibles became more apparent during the second and fourth weeks of consolidation, when levels were noted to be nearly 140% and 160% of controls, respectively. In contrast, osteocalcin expression in mandibles harvested from acutely lengthened animals remained low (less than 50% of sham-operated levels) throughout the experiment.

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insight to the complex regulation of neovascularization during DO. For example, several studies have indicated that VEGF Flt-1 and Flk-1/KDR receptors have different signal transduction properties.^{86,87} Flk-1/KDR, but not Flt-1, has been shown to initiate endothelial chemotaxis and mitogenesis.⁸⁶ Furthermore, the angiopoietins may potentiate the effects of VEGF, where VEGF + Ang-1 promotes vascular network maturation, whereas VEGF + Ang-2 destabilizes the endothelial membrane, facilitating neovascularization.⁸⁸ Finally, indirect evidence indicates that Tie-1 receptor signaling is essential for vascular endothelial cell integrity, whereas the Tie-2 receptor recruits and sustains periendothelial support cells.⁸⁸ Further investigation is necessary to understanding the complex regulation and coordinated control of these angiogenic factors.

Mechanical Forces

Much research has been devoted toward characterizing the association between stress and strain patterns with bone formation. Correlating tensile force measurements with histology, Loba and colleagues demonstrated that the greatest amount of bone formation occurs during active distraction, the period of greatest strain.⁸⁹ Loba and colleagues went on further to characterize the forces of distraction, using finite element analysis models created from three-dimensional computed tomography image data of rat mandibles at different phases of DO.⁹⁰ The models described patterns of moderate hydrostatic stress within the gap, predictive of intramembranous ossification, and patterns of mild compressive stress in the periphery, consistent with endochondral ossification. These data derived from finite element analysis were consistent with previous histologic findings.

Great interest surrounds research characterizing how mechanical forces may be translated into molecular signals that promote bone regeneration. Tong and colleagues described the role of focal adhesion kinase (FAK), a regulator of the integrin-mediated signal transduction cascade, in DO.⁹¹ In a rat model of mandibular DO, Tong and colleagues demonstrated the immunolocalization of FAK in regions of new bone formation secondary to distraction, but which was absent in the control groups where new bone formation occurred without distraction. Similarly, recent work has also co-localized c-SRC, a kinase involved with activation of the mechanical transduction complex (p130), in regions of bone regeneration secondary to DO.⁹² While signaling molecules involved with transduction of mechanical forces are being identified, further work clarifying the mechanisms of these messenger molecules is required to understand the influence of the mechanical environment on skeletal tissue engineering.

Conclusions

The future of craniofacial DO lies in continued rigorous clinical and basic science research. For example, Ilizarov's original meticulous histologic examination revealed that mechanical strain could stimulate the formation of strong viable regenerate bone in the wake of the distracted segment.¹ This observation set the foundation for more advanced molecular analyses of gene expression during DO. These data have already led to the application of novel recombinant proteins and gene modified distraction protocols.^{38,62,93} However, many issues still remain unresolved. For example, much remains to be elucidated about the biomechanical transduction of the tension-stress effect delivered to osteogenic cells during DO. Although this biomechanical transfer of force appears to be the central event leading to a well-orchestrated cascade of events mediating the bony adaptive response, we are only beginning to understand how cells perceive this force, interpret it, and transmit intracellular messages. Understanding the molecular events leading to successful DO has important clinical implications, since it is a fundamental step toward the evolution of targeted therapeutic interventions designed to accelerate osseous regeneration during DO. Indeed, the development of novel recombinant proteins, gene transfer techniques, minimally invasive approaches, biodegradable multiplanar distraction devices, and the identification of objective end points will propel the field of craniofacial DO by decreasing the distraction and consolidation times, reducing complications (eg, fibrous union), and optimizing patient outcomes.

Distraction osteogenesis is now entering a new era of the three-dimensional computer-mediated preoperative planning and outcomes assessment.^{94,95} Computer-based three-dimensional scans will reconstruct the craniofacial skeleton and enable surgeons to virtually design, plan, and execute osteotomies. Ultimately, the application and animation of virtual distractors together with fundamental biomolecular data will help guide physician and patient expectations.

Acknowledgment

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